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August 1965

DATA COMPILATION AND EVALUATION OF SPACE SHIELDING PROBLEMS

DOSE CALCULATIONS IN SPACE VEHICLES

VOLUME II

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FOREWORD

Volumes I and II, ER 7777, Data Compilation and Evaluation of Space Shielding Problems, comprise a technical summary report of the study performed for Contract NAS 8-11164 under the direction of the George C. Marshall Space Flight Center, NASA, Huntsville, Alabama. Special acknowledgement is due the technical contract monitor, Martin O. Burrell of the Research Projects Division, who suggested the charged particle range approximation and the radiation transport method. Mr. Burrell also furnished solar flare and other data. J. C. Whiten, Large Vehicle and Propulsion Engineering, forwarded data on vehicle configurations and mission trajectories. Frank T. Bly, Lockheed-Georgia Company, made several important contributions to the design of the Geometry program and the approximation of range data. C. C. Douglass, Lockheed-Georgia Company, performed the initial programming of the Geometry program and the Geometry Test program. Mr. Douglass also developed DIP, the Data Input Program, which condenses and simplifies data preparation for several of the computer codes described herein.

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1.0 INTRODUCTION

Volume II of this report describes a computer program system which provides an estimate of proton and alpha particle dose within realistic space vehicle configurations. An application of the program system is presented for several interplanetary missions. Program descriptions, operating instructions, and test cases are given.

Section 2 contains the results of proton dose calculations for three vehicular configurations. Two of the configurations are interplanetary vehicles containing seven man models; the third is an eight man command module. The sources for the interplanetary missions are composite proton spectra representing solar flare activity during the 1954-64 solar cycle. Dose is calculated at eleven positions in the interplanetary configurations and ten positions in the command module. The effects of equipment shielding and body self-shielding are illustrated.

Sections 3, 4, and 5 contain descriptions and operating instructions for the Geometry program, the Geometry Test program, and the Dose program. The Geometry program manipulates geometric data and computes penetration thicknesses. A variety of configurations and material arrangements may be analyzed. The Geometry Test program scans the input geometric data for character and format errors, checks for certain logical inconsistencies, and plots, off-line, selected cross sections of the geometric representation in order that a visual inspection of the geometric configuration may be made. The Dose program combines radiation source data and geometric data and computes the dose at the specified detector points. The transport method treats multilayered shields and approximates the secondary contributions to the dose.

Section 6 describes the Mission Flux Code. The Mission Flux Code is similar to a previous Lockheed code except that fluxes are interpolated in B-L coordinates. The program integrates trapped belt proton flux in twelve energy groups and electron

flux in eight energy groups over a trajectory. The trajectory may be input directly, or, in the case of orbital missions, may be computed automatically from orbital parameters.

Appendix A.1 describes the data format for the Data Input Program (DIP) which is utilized by several of the programs detailed in this report. Appendix A.2 contains test case input data and output listings for each program.

2.0 MISSION DOSE CALCULATIONS

This section presents the results of dose calculations using the Dose program, Section 5, in conjunction with the Geometry program, Section 3. Doses inside and outside two configurations of interplanetary vehicle are exhibited in Section 2.3. The doses are computed at eleven detector points associated with each vehicle. The radiation sources represent proton spectra due to solar flare activity during the mission. Three launch dates were employed for each vehicle: October 9, 1977, December 26, 1981, and April 16, 1986. These six launches are all missions to the planet Mars with durations of more than a year.

A seventh mission was analyzed in which the hydrogen tank of the "wet" configuration, Section 2.1, was full during the outbound voyage and empty during the inbound. Further calculations were executed with the interplanetary vehicle configurations with a representative flare as a radiation source. The representative flare was also used as a proton source with a command module configuration. In this study, the shield thickness, amount of inboard equipment, and number of man models was varied and the dose at ten detector locations calculated.

The Geometry program was employed only three times for the calculations presented in this section: once for each of the interplanetary vehicle configurations and once for the command module configuration. The computer time required to produce the three geometry tapes for the 32 detector positions is approximately 40 minutes. The computer time required by the Dose code to produce the 181 dose calculations presented in section 2.3 is approximately 40 minutes.

2.1 GEOMETRIC CONFIGURATIONS

Three geometric configurations are employed for the dose calculations obtained from the Dose code. These configurations are two interplanetary vehicle concepts

and a command module concept. The two interplanetary vehicles are referred to as the "wet" and "dry" configurations. The wet configuration, Figure 2-1, has a command module and most of the equipment module inserted in a 30 foot diameter liquid hydrogen tank. Below the hydrogen tank and attached to the vehicle stem are four mission modules. Inserted in the base of the vehicle stem is an Earth re-entry module. The hydrogen tank has a multi-layered wall consisting of 2.5 lbs/ft^2 Al. meteroid bumper, .5 lbs/ft^2 super insulation, 2.5 lbs/ft^2 Al. meteoroid bumper, and .15 inch Al. skin. The tank is filled with liquid hydrogen at a density of 4.37 lbs/ft^3. The command module and the equipment module are surrounded by a multi-layered pressure shell consisting of .1 inch Al., .5 lbs/ft^2 super insulation, and .1 inch Al.

The command module has two sections, a duty station and a rest area, separated by a polyethylene floor 3 inches thick. The floor has an opening permitting passage between the two areas. The duty station contains three man models seated at an instrument console and two storage lockers. The rest area contains four polyethylene bunks, 2 inches thick, and one supine man model in one of the bunks. The floor of the rest area is two layers of water and polyethylene with a polyethylene plug in the center to permit passage to and from the equipment module tunnel. The command module fits inside the pressure shell and is a cylinder with an inside diameter of 104.8 inches.

Directly beneath the command module is a cylindrical equipment module. The equipment module has a four foot diameter tunnel through the center. The tunnel is surrounded by equipment boxes with an average density of 25 lbs/ft^3. A standing man model has been placed approximately in the middle of the tunnel.

The next section of the vehicle stem contains a void 8 feet in length. The four mission modules are attached to this section of the stem. Each mission module has multi-layered walls consisting of 1 lb/ft^2 Al. meteoroid bumper, .2 lbs/ft^2 super

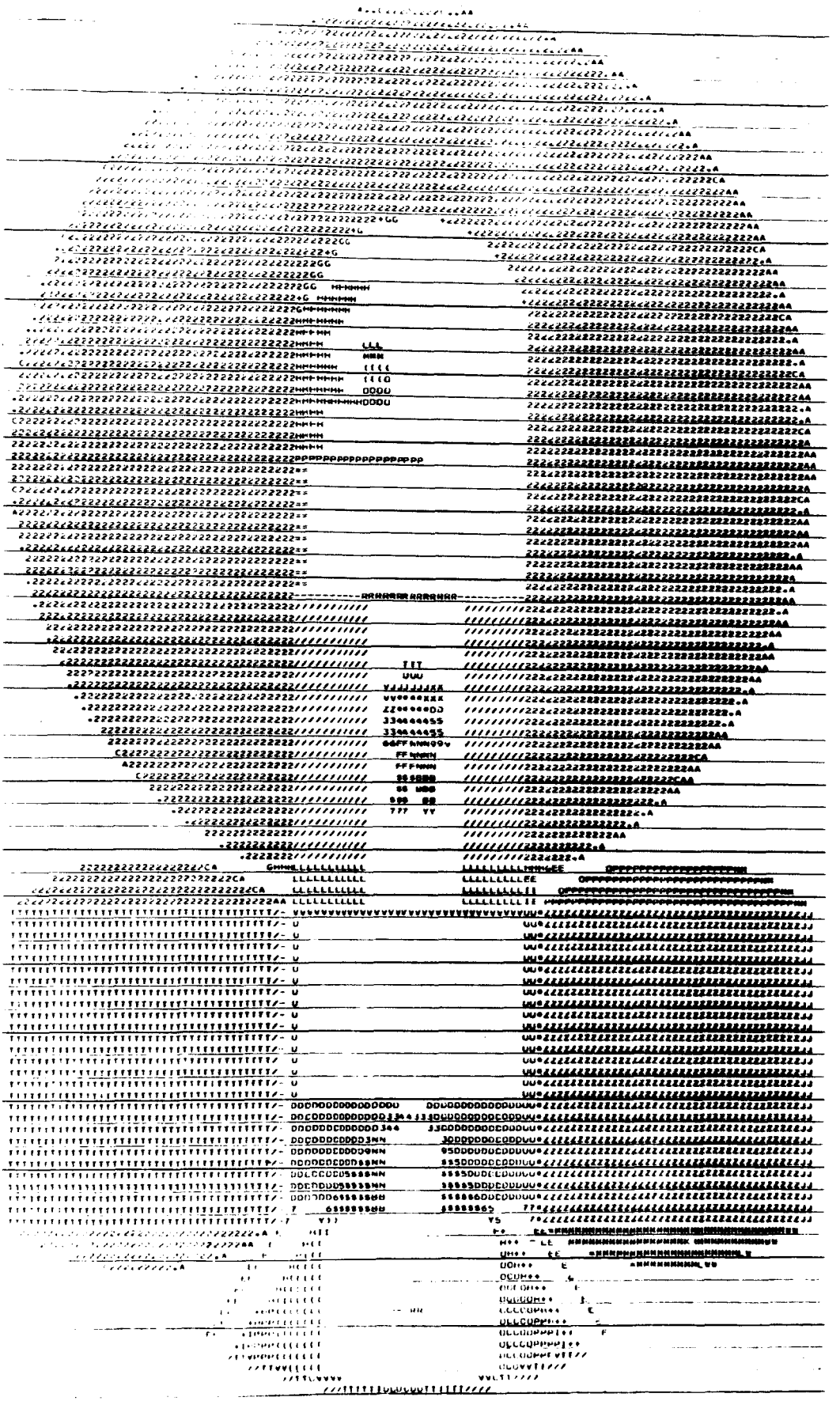


FIGURE 2-1 VERTICAL CROSS SECTION THROUGH WET CONFIGURATION

insulation, 1 lb/ft^2 Al. metheoroid bumper, and .15 inch Al. skin. The material contained in the mission modules has a density of 10 lbs/ft^3.

At the base of the vehicle stem is a cylindrical section of water four feet long terminating in a flared aluminum skirt. The Earth reentry module is attached at this section. This module consists of multi-layered walls, equipment bays, docking mechanism, off-axis ablative heat shield, and a seated man model. In addition to the man models inside the vehicle and reentry module, a man model, in a simulated space suit, Figure 2-2, is outside in the vicinity of the hydrogen tank.

The dry configuration, Figure 2-3, is similar to the wet configuration except that the hydrogen tank has been removed, the pressure shell has been removed, the command module has been surrounded by a 7.6 inch polyethylene shield, and the modules have been rearranged. The man models are in the same locations with respect to the module with which each is associated; the man model outside is placed in the vicinity of one of the mission modules.

The command module configuration, Figure 2-4, used for studies with the representative flare is similar to the command module in the dry configuration. This command module, however, contains eight man models with two detectors in each of four of the models and one detector in each of two man models. There are three man models seated at the instrument console in the duty station, four supine man models in the bunks in the rest area, and one man model standing in the passageway between the duty station and the rest area.

The man models are composed of homogeneous tissue. The models are constructed in two attitudes, standing and sitting. The standing model is also used for the prone and supine positions. A cross section of the standing man model in a simulated space suit is shown in Figure 2-2. A drawing of the seated man model is shown in Figure 2-5.

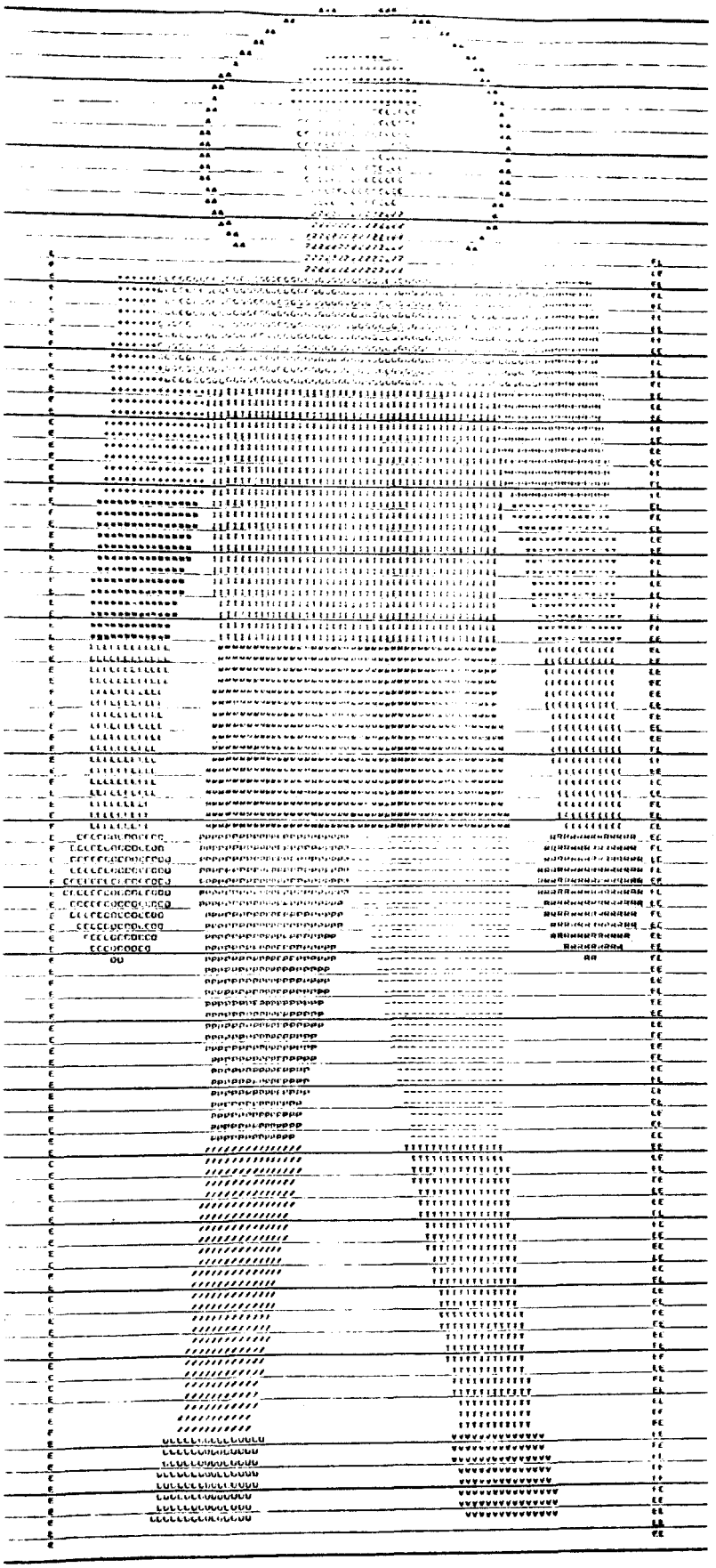


FIGURE 2-2 MAN MODEL IN SIMULATED SPACE SUIT

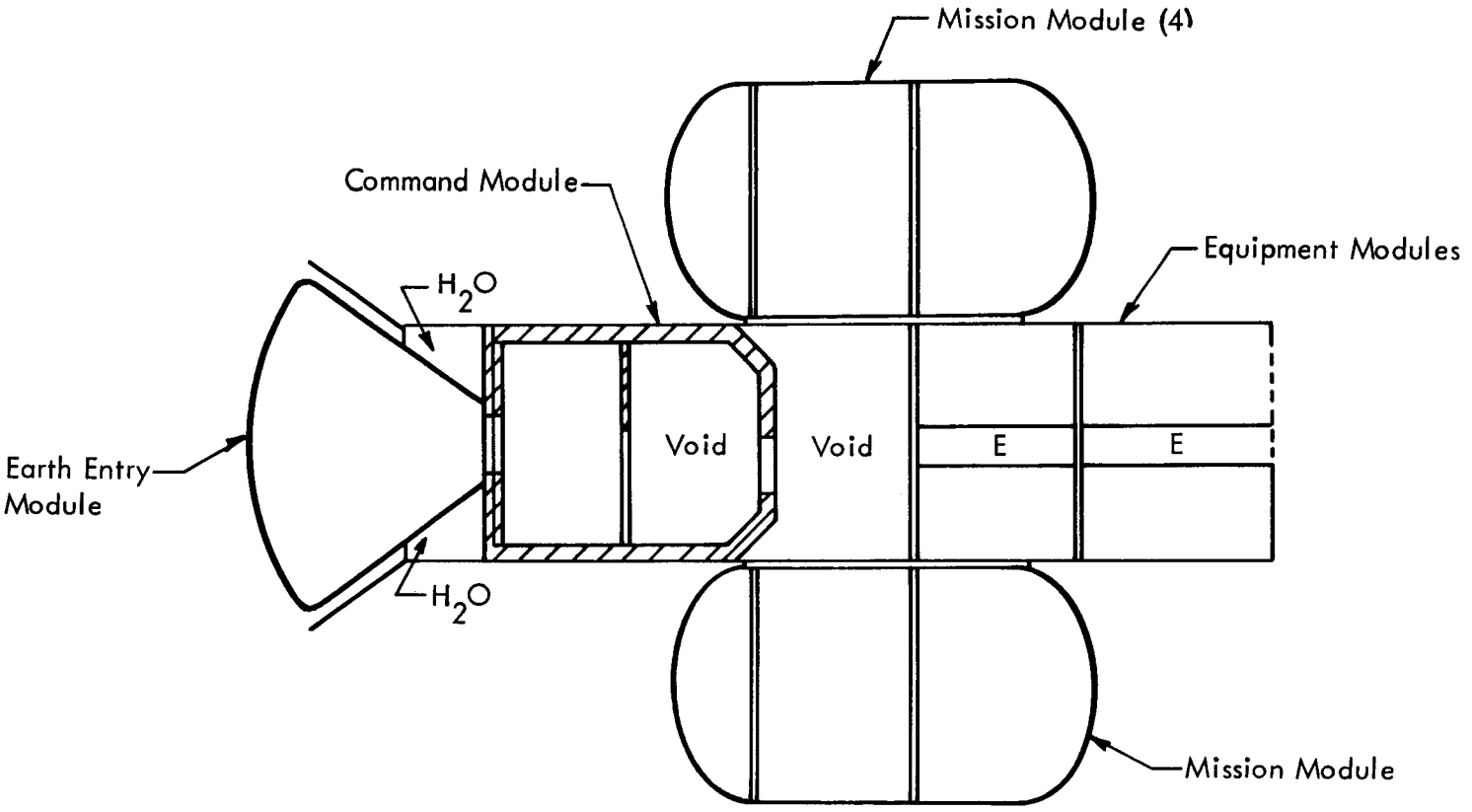


FIGURE 2-3 VERTICAL CROSS SECTION THROUGH DRY CONFIGURATION

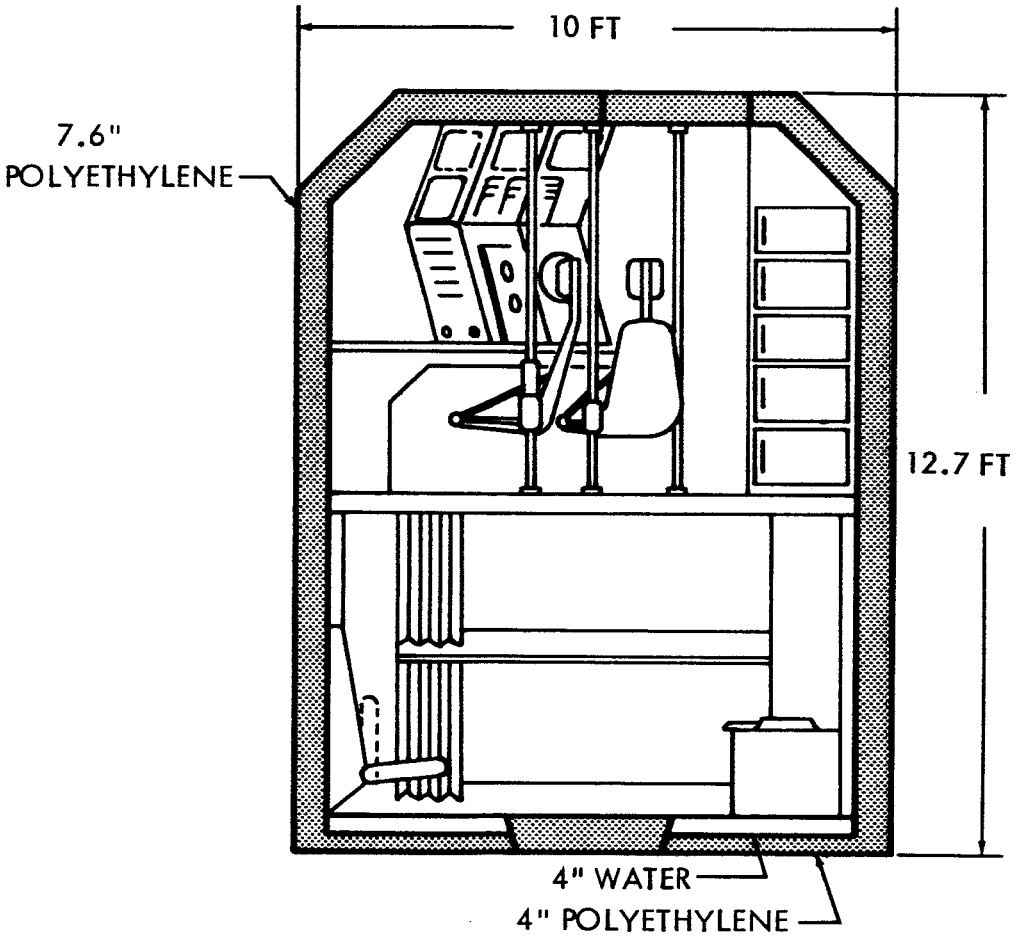


FIGURE 2-4 EIGHT MAN MODULE

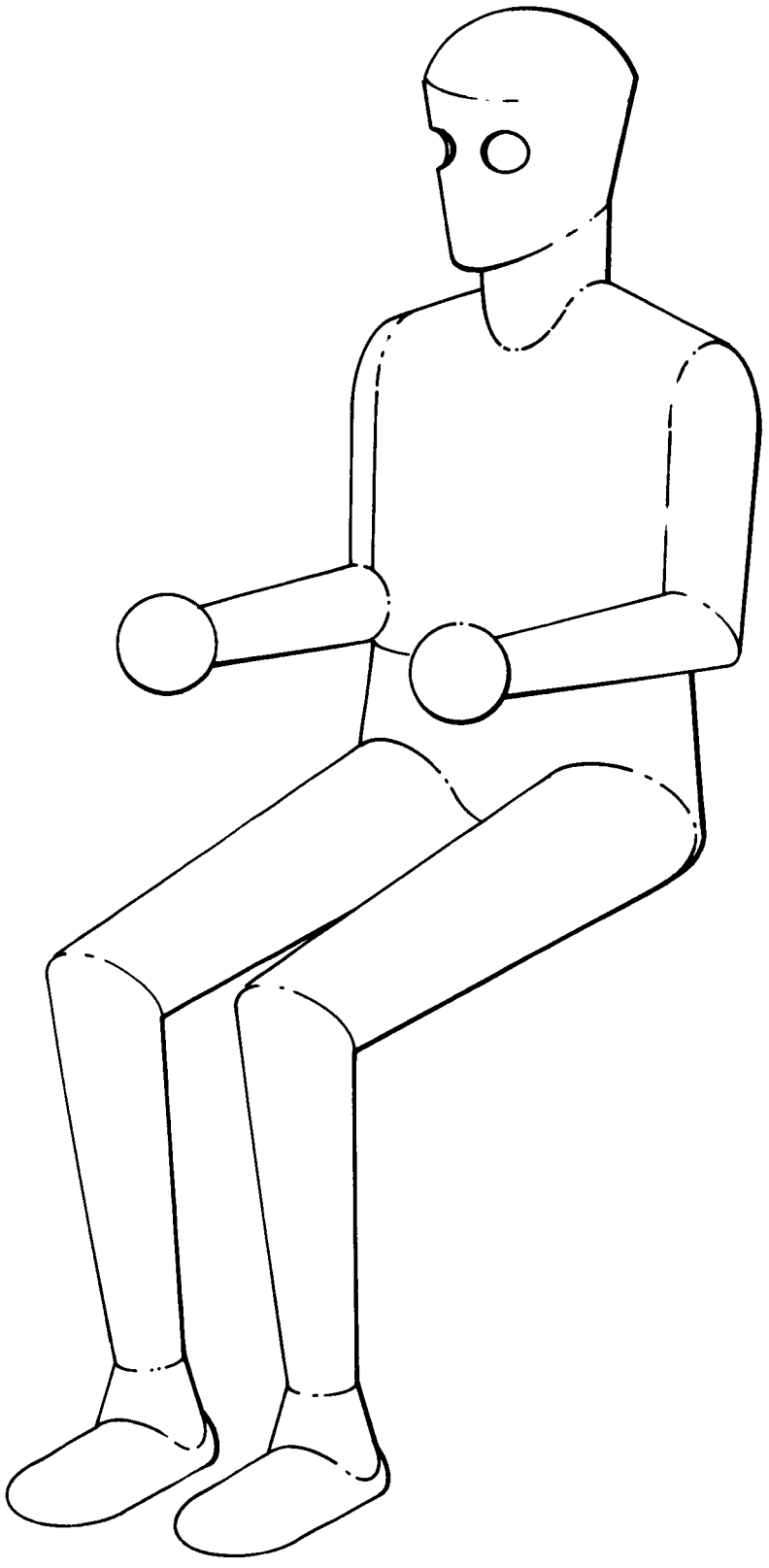


FIGURE 2-5 SEATED MAN MODEL CONFIGURATION

2.2 PROTON SOURCE SPECTRA

Four isotropic proton source spectra are employed in this study. One of the sources is a representative solar flare, and three are composite sources simulating the solar flare activity throughout the duration of the missions. The representative flare source is obtained from Reference 1. The proton flux, differential in rigidity, is given by equation 2-1.

$$\frac{dP}{dp} = 4.516 \times 10^{7} \times \exp(-p/80) \quad \frac{\text{Protons}}{\text{cm}^2\text{-MV-ster.}} \tag{2-1}$$

The composite sources are obtained from a computer program provided by Marshall Space Flight Center, NASA, Huntsville, Alabama, and modified for the purposes of this study. A basic assumption of this program is that succeeding eleven year solar cycles will have the same flare magnitude and distribution as the period January 1954 to December 1964. Further, proton fluxes due to each flare are distributed uniformly over the calendar year in which that flare occurred. The proton flux for the mission is given by

$$P = \sum_i \left(\frac{r_e}{r_i}\right)^2 P_i \tag{2-2}$$

where r_e = radius of the Earth's orbit

r_i = sun-vehicle distance during the i^{th} day of the mission

P_i = proton flux during the i^{th} day of the mission

The proton flux spectra representing the solar flare activity integrated over mission time are compiled in Table 2-1. Cosmic ray sources and trapped radiation sources are not included.

TABLE 2-1 MISSION FLUX SPECTRA*

E(MeV)	Launch Dates		
	October 9, 1977	December 26, 1981	April 16, 1986
10	3.0459+7**	4.5309+8	2.4544+5
30	3.3550+6	1.6166+7	5.2484+3
80	4.7361+5	8.7997+5	1.6949+2
150	1.5349+5	1.3930+5	1.8777+1
300	3.4156+4	1.8505+4	1.6597+0
500	1.2384+4	4.2091+3	2.7769-1
700	6.3506+3	1.5909+3	8.5528-2
1000	3.1293+3	5.6817+2	2.4544-2

* Flux units are $\frac{P}{MeV\text{-}cm^2\,ster}$

** The sign and digit following each number represents the power of ten multiplying that number.

2.3 DOSE CALCULATION

The dose estimates presented here result from applying the Dose program to the configurations of Section 2.1 and the sources of Section 2.2. The detectors located in man models are placed in the right eye socket and approximately in the center of the abdomen for both the sitting and standing positions. One detector is located in the center of a mission module for both the wet and dry configurations.

Table 2-2 illustrates doses within the eight man command module of Figure 2-4 due to the solar flare given in Equation 2-1. Here, the effect of changing the outer shield from 7.6 inches to 1.0 inches of polyethylene is shown. The first row gives doses with only the shield taken into account; i.e., the densities of equipment and man models are set to zero. The second row represents dose estimates with only man model densities set to zero. The third row represents doses for the entire configuration. For this flare spectrum, the presence of equipment and body self-shielding lowers dose by a factor of 2 to 2.5 for eye detectors and lowers dose by a factor of

TABLE 2-2 SOLAR FLARE DOSE (RAD) - EIGHT MAN MODULE

$$\frac{dP}{dp} = 5.675 \times 10^{8} \exp(-p/80) \frac{\text{Protons}}{\text{cm}^2\text{-MV}}$$

Detectors	1E	1A	2E	2A	3E	3A	4E	5E	5A	6E
7.6" Polyethylene										
Shield Only	2.87	2.87	1.49	2.07	3.00	2.51	2.36	1.59	2.08	1.62
Shield + Equipment	1.82	1.92	1.36	1.80	2.18	2.10	1.66	1.43	1.80	1.44
Shield + Crew + Equipment	1.17	0.29	0.78	0.20	1.24	0.30	1.28	0.82	0.20	0.84
1.0" Polyethylene										
Shield Only	203.	194.	98.0	122.	198.	165.	176.	107.	124.	105.
Shield + Equipment	83.5	95.5	91.6	96.5	116.	115.	88.6	98.1	97.4	89.5
Shield + Crew + Equipment	30.4	1.87	47.6	1.16	42.1	2.12	54.4	48.9	1.23	49.7

E = detector in eye
A = detector in abdomen
1 = middle crew member at instrument console
2 = crew member in top bunk, head under instrument console
3 = crew member in hatchway
4 = right crew member at instrument console
5 = crew member in top bunk, feet under instrument console
6 = crew member in bottom bunk, head under instrument console

10 for gut detectors inside 7.6 inches of polyethylene shielding. The corresponding factors for the thin shield are 2 to 7 and 80 to 100.

Table 2-3 presents dose estimates within the wet and dry configurations for the same flare. The effect of emptying the liquid hydrogen tank is illustrated.

Table 2-4 shows the estimated doses for the wet configuration over three Mars missions. No credit is taken for biological recovery. The sources of Table 2-1 are used. The vehicle orbits Mars for twenty days during each mission. The proton fluxes are reduced by one half during this period due to planetary screening. The 1977, 1981, and 1986 mission trajectories approach the sun within .4864, .5245, and .6502 astronomical units respectively during the return to earth. The 1986 mission exhibits low doses because it occurs at the minimum of the solar activity cycle.

Table 2-5 shows the estimated doses for the dry configuration over three Mars missions. Conditions are identical to those of Table 2-4 except for the vehicle configuration.

Table 2-6 depicts the estimated doses in the wet configuration for the 1977 mission. In this case, the liquid hydrogen tank is full during the outbound trajectory and empty during the inbound trajectory. In Table 2-4, the liquid hydrogen tank is full during the entire mission.

TABLE 2-3 MISSION VEHICLE DOSES (RADS)[1]

Detector Location	Wet Configuration Liquid Hydrogen Density Gms/cm^3			Dry Configuration
	0.07	0.035	0.0	
Middle Crewman at Instrument Console				
(Eye)	0.114	0.54	8.817	0.362
(Abdomen)	0.051	0.204	1.689	0.169
Crewman in Top Bunk				
(Eye)	0.073	0.433	26.89	0.562
(Abdomen)	0.039	0.128	0.861	0.131
Crewman in Reentry Vehicle				
(Eye)	2.783	2.783	2.783	3.263
(Abdomen)	0.289	0.289	0.289	0.377
Crewman in Equipment Module Tunnel				
(Eye)	0.051	0.154	0.782	52.12
(Abdomen)	0.036	0.076	0.236	0.241
Crewman Outside Looking at Hydrogen Tank*				
(Eye)	274.1	274.2	278.4	204.0
(Abdomen)	2.988	3.003	3.436	3.134
Detector in Mission Module **	0.800	0.801	0.819	0.857

* Looking at mission module in Dry Configuration

** Water receiver; all other detectors are tissue receivers.

1. $dP/dp = 5.675 \times 10^8 \times \exp(-p/80) \frac{\text{Protons}}{\text{cm}^2\text{-Mv}}$

TABLE 2-4 MARS MISSION DOSE (RADS/MISSION)*

WET CONFIGURATION

Detector Location	October 9, 1977[1]	December 26, 1981[2]	April 16, 1986[3]
Middle Crewman at Instrument Console			
(Eye)	4.954	1.879	1.38(-4)
(Abdomen)	3.953	1.354	0.92(-4)
Crewman in Top Bunk			
(Eye)	4.216	1.505	1.06(-4)
(Abdomen)	3.472	1.131	0.74(-4)
Crewman in Reentry Vehicle			
(Eye)	9.089	6.319	7.47(-4)
(Abdomen)	5.012	2.215	1.85(-4)
Crewman in Equipment Module Tunnel			
(Eye)	3.827	1.304	0.89(-4)
(Abdomen)	3.425	1.120	0.74(-4)
Crewman Outside Looking at Hydrogen Tank			
(Eye)	129.0	489.7	1.516(-1)
(Abdomen)	12.39	8.315	9.15(-4)
Detector in Mission Module**	8.789	4.547	4.15(-4)

1 - Total duration - 442 days. 2 - Total duration - 456 days. 3 - Total duration - 444 days.

* Does not include cosmic ray dose.

** Water receiver; all other detectors are tissue receivers.

TABLE 2-5 MARS MISSION DOSE (RADS/MISSION)*

DRY CONFIGURATION

Detector Location	October 9, 1977[1]	December 26, 1981[2]	April 16, 1986[3]
Middle Crewman at Instrument Console			
(Eye)	6.257	2.806	2.35(-4)
(Abdomen)	4.985	1.985	1.53(-4)
Crewman in Top Bunk			
(Eye)	6.656	3.257	2.92(-4)
(Abdomen)	4.599	1.775	1.33(-4)
Crewman in Reentry Vehicle			
(Eye)	10.31	7.356	8.75(-4)
(Abdomen)	5.690	2.631	2.26(-4)
Crewman in Equipment Module Tunnel			
(Eye)	32.66	82.68	2.23(-2)
(Abdomen)	6.044	2.54	2.01(-4)
Crewman Outside Looking at Mission Module			
(Eye)	100.7	355.8	1.08(-1)
(Abdomen)	13.02	8.723	9.59(-4)
Detector in Mission Module**	9.429	4.894	4.47(-4)

1 - Total duration - 442 days. 2 - Total duration - 456 days. 3 - Total duration - 444 days.

* Does not include cosmic ray dose.

** Water receiver; all other detectors are tissue receiver.

TABLE 2-6 MARS MISSION DOSE (RADS/MISSION)*

Detector Location	Outbound LH_2 Tank Full[1]	Inbound LH_2 Tank Empty	Total
Middle Crewman at Instrument Console			
(Eye)	.7724	18.14	18.91
(Abdomen)	.6163	9.445	10.06
Crewman in Top Bunk			
(Eye)	.6573	25.01	25.67
(Abdomen)	.5414	7.493	8.034
Crewman in Reentry Vehicle			
(Eye)	1.417	7.709	9.126
(Abdomen)	.7815	4.263	5.044
Crewman in Equipment Module Tunnel			
(Eye)	.5967	7.310	7.907
(Abdomen)	.5339	5.062	5.596
Crewman Outside Looking at Hydrogen Tank			
(Eye)	20.20	114.2	134.4
(Abdomen)	1.932	12.63	14.56
Detector in Mission Module**	1.370	7.761	9.131

1 - Includes 20 day "stay time" at Mars. Outbound duration - 218 days; inbound duration - 224 days.

* Does not include cosmic ray dose. Launch date - October 9, 1977.

** Water receiver; all other detectors are tissue receivers.

3.0 GEOMETRY PROGRAM

The purpose of the Geometry Program is to discover the shielding afforded a detector by a configuration of materials. To realize this purpose, a set of volume elements, representing the configuration, is constructed, and a set of vectors associated with each detector is generated. The volume elements are constructed and the vectors are generated automatically by the Geometry Program from input data. Each volume element is defined by its material composition, density, and bounding surfaces. Four types of volume element boundaries may be used:

- planar surfaces
- ellipsoidal surfaces
- elliptic cylindrical surfaces
- elliptic conical surfaces

The coefficients for the algebraic representation of the planar and quadric surfaces are calculated by the Geometry Program. Data for these surfaces consists of a few points, lengths, and ratios that may be obtained from engineering drawings. A planar surface is determined by the coordinates of three non-collinear points; each of the quadric surfaces is determined by three points and at most three parameters. The Geometry Program derives the quadric surface coefficients in a coordinate system in which the algebraic expression for the surface has a canonical form. The program then obtains the transformation necessary to compute the surface coefficients in the coordinate system common to the entire configuration. A maximum of twenty-five surfaces, each with unrestricted orientation, may be used to bound a volume element. Each volume element requires, in addition to the bounding surface data, the number of planar surfaces, the number of quadric surfaces, a material number, the density, and the coordinates of an internal point.

In order to reduce the amount of data required to specify a set of volume elements,

a feature called "embedding" is employed. Embedding permits volume elements to be located partially, or completely within other volume elements. If two or more volume elements compete for a common region of space, dominance is assigned by the order of data input. The number of volume elements which may compete for a common region of space is presently restricted to twenty-five.

A vector array associated with each dose point (detector) is generated. A solid angle is determined for each vector of the array. This solid angle is less than an input criterion. The solid angle criteria may be varied over the configuration to give added importance to selected regions. The number of vectors assigned to each detector may be arbitrarily increased by decreasing the solid angle criteria. The location of each detector and the total number of detectors are unrestricted.

The segments of each vector which lie within volume elements are found and arranged in order from detector outward. The data defining detector location, vector direction, solid angle, and material penetrations are stored in binary form on magnetic tape for use by the Dose Code.

3.1 REPRESENTATION OF GEOMETRIC CONFIGURATION

A geometric configuration consists of a set of volume elements. Each volume element is defined by its bounding surfaces, material number, density, and the coordinates at any point internal to the volume element. A volume element must be completely enclosed by the surfaces defining it. Each surface divides all space into two regions; all internal points of a volume element must be in the same region with respect to each surface associated with that volume element.

There are certain combinations of surfaces for which points outside the desired volume element satisfy the above conditions. For example, Figure 3-1 exhibits a region, (a), which is inside the cylinder and outside both spheres. However, regions

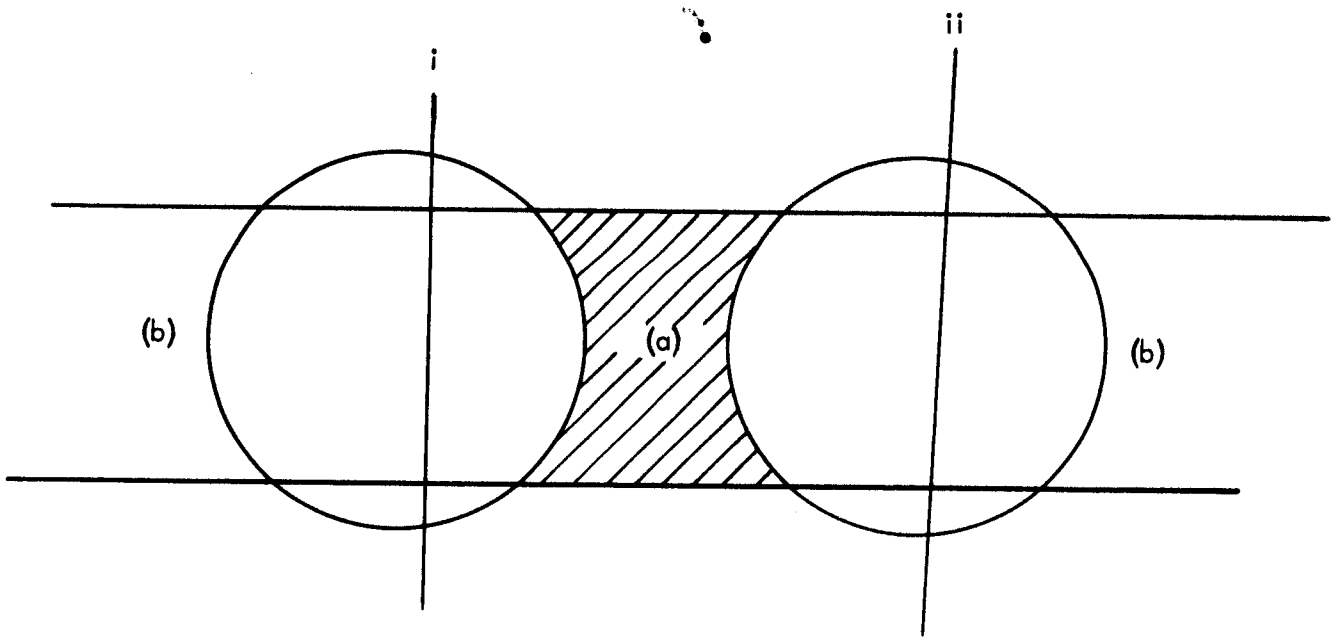


FIGURE 3-1 VOLUME ELEMENT DEFINITION

(b) are also inside the cylinder and outside both spheres. If only region (a) is the volume element desired, then planes i and ii must be included as bounding surfaces. Note that a volume element need not be a connected region. In general, care must be taken to define the desired volume element and only that volume element. Cones are particularly hazardous in this respect because both nappes comprise the surface.

The Geometry Program initially calculates coefficients for equations which describe bounding surfaces of the volume elements. The data required for plane surfaces are the coordinates of three non-collinear points in the plane. The data required for quadric surfaces are the coordinates of three points (the first two on the axis of the quadric and the third on the surface and on the major or minor axis of the elliptic cross-section), an integer indicating the type of quadric, the length(s) of the semi-axis (axes) not associated with the third point, and, in the case of cones, the tangent of the cone half-angle in the plane defined by the axis and the third point.

Using the coordinates of the three non-collinear points (x_i, y_i, z_i) in the plane, the equation for the plane is obtained.

$$\frac{A}{S}x + \frac{B}{S}y + \frac{C}{S}z = \frac{D}{S} \qquad (3\text{-}1)$$

where

$$A = \begin{vmatrix} 1 & y_1 & z_1 \\ 1 & y_2 & z_2 \\ 1 & y_3 & z_3 \end{vmatrix} \qquad B = \begin{vmatrix} x_1 & 1 & z_1 \\ x_2 & 1 & z_2 \\ x_3 & 1 & z_3 \end{vmatrix}$$

$$C = \begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix} \qquad D = \begin{vmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{vmatrix}$$

and

$$S = \left[A^2 + B^2 + C^2 \right]^{1/2}.$$

The coefficients of x, y, and z in Equation 3-1 are the direction cosines of the normal to the plane. The signs of the coefficients are chosen so that the normal is directed away from the internal points of the volume element.

The coefficients of a quadric surface,

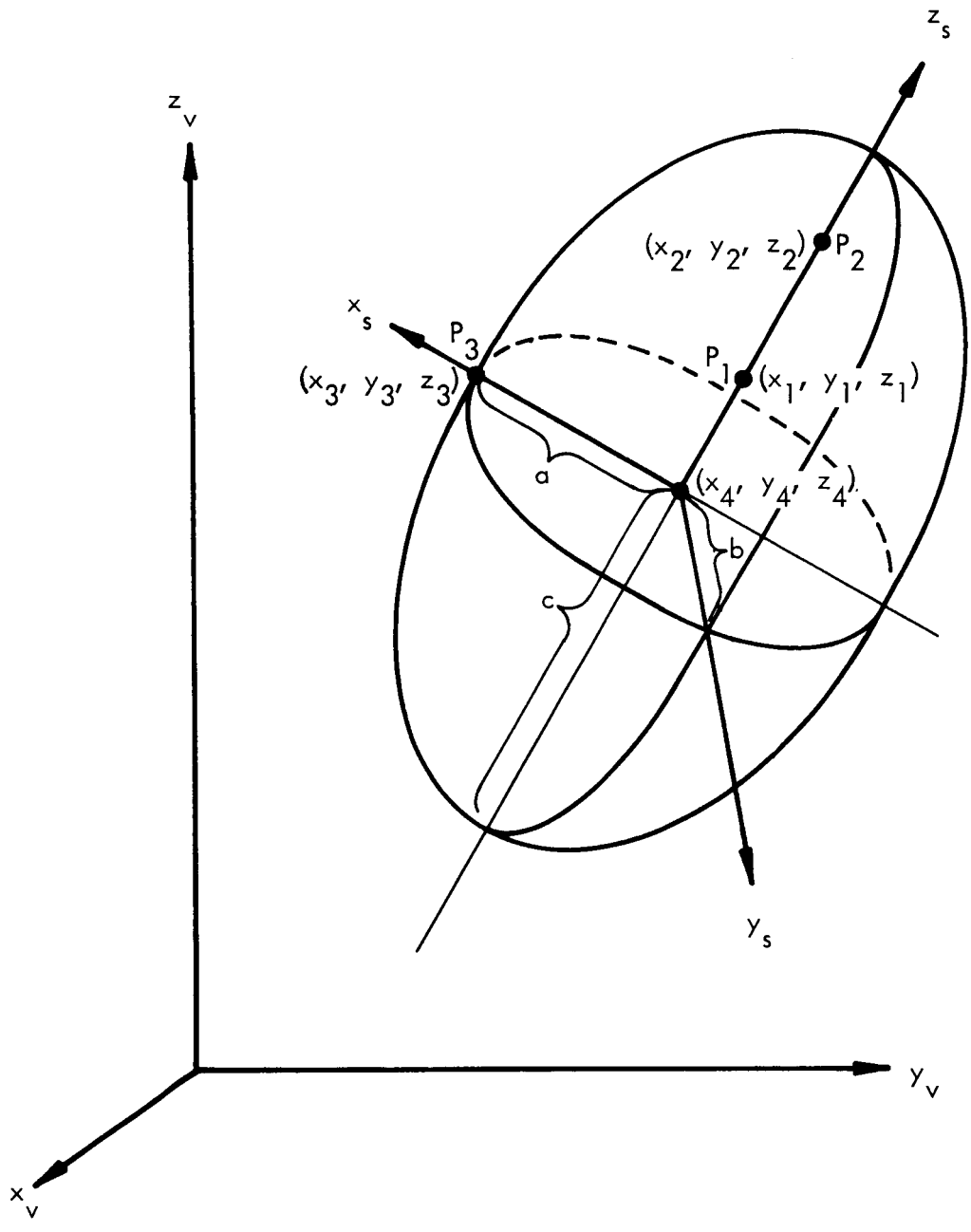
$$Ax^2 + By^2 + Cz^2 + Dxy + Exz + Fyz + Gx + Hy + Pz + Q = 0,$$

are determined by the coordinates of three special points, P_1, P_2, and P_3, and two or three parameters, illustrated in Figures 3-2, 3-3, and 3-4. The equation of the quadric surface is first acquired in a coordinate system in which the equation has the form:

$$A^* x_s^2 + B^* y_s^2 + C^* z_s^2 = D^* \qquad (3\text{-}2)$$

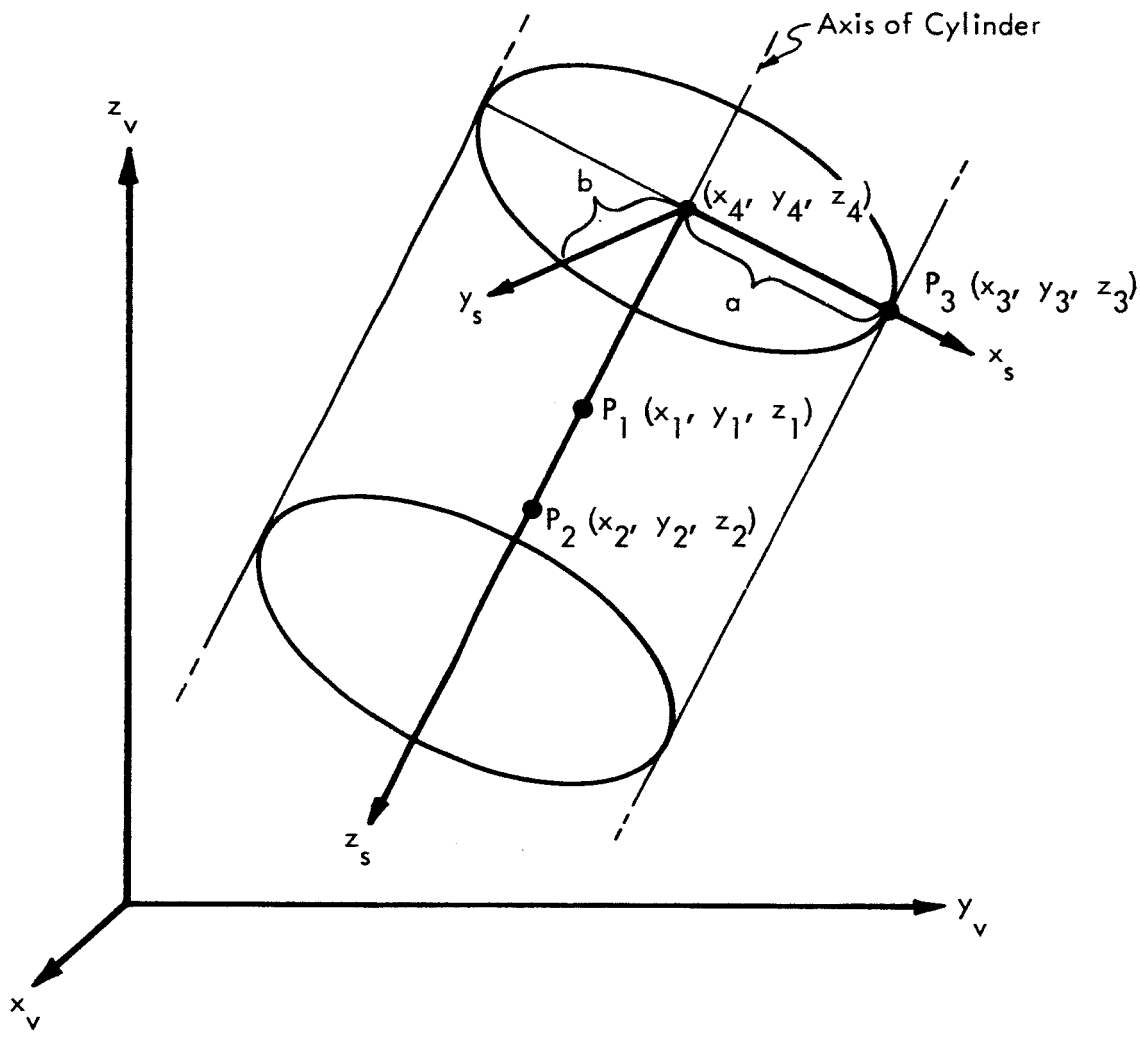
This coordinate system will be referred to as the canonical system.

The first two points must be on the axis of the surface in the case of the cylinder and the cone; in the case of the ellipsoid, these two points may be on any axis. These two points are used to define the z-axis of the coordinate system in which



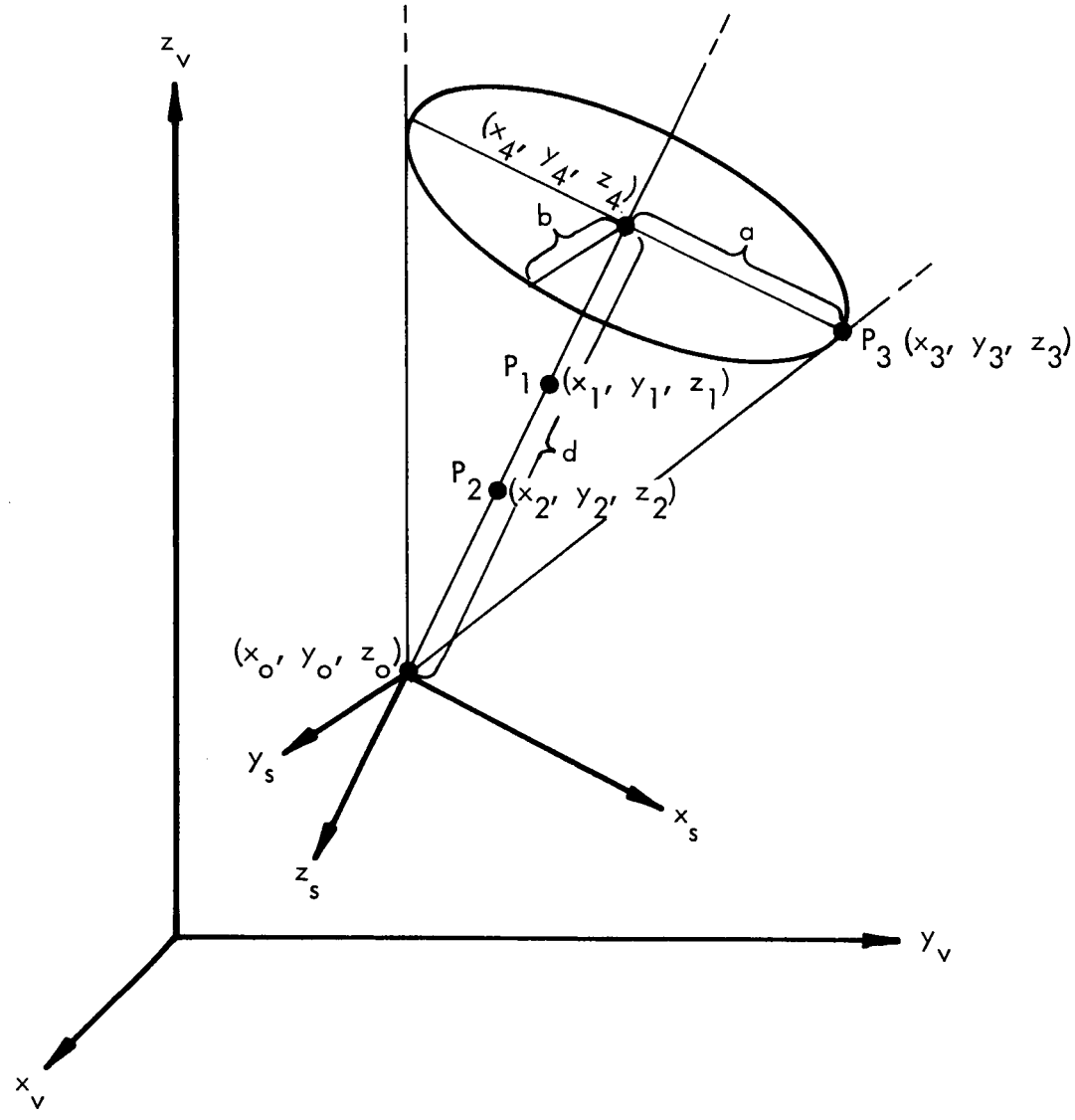
x_v, y_v, and z_v are the vehicle system coordinate axes; x_s, y_s, and z_s are the coordinate axes of the canonical system associated with the surface. a, b, and c are the semi-axes of the quadric.

FIGURE 3-2 ELLIPSOIDAL SURFACE



x_s, y_s, and z_s are coordinate axes of the canonical system; x_v, y_v, and z_v are coordinate axes of the vehicle system. Here, the line segment a is the semi-major axis of the elliptic cross-section and b the semi-minor axis.

FIGURE 3-3 ELLIPTIC CYLINDRICAL SURFACE



x_v, y_v, and z_v are the vehicle system coordinate axes; x_s, y_s, and z_s are the coordinate axes of the canonical system associated with the surface. a and b are the semi-axes of the quadric.

FIGURE 3-4 ELLIPTIC CONICAL SURFACE

the equation of the surface has the form 3-2. The direction cosines of this axis in the vehicle coordinate system are:

$$\cos\alpha_z = (x_2 - x_1) \Big/ \left[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2\right]^{1/2},$$

$$\cos\beta_z = (y_2 - y_1) \Big/ \left[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2\right]^{1/2},$$

and

$$\cos\gamma_z = (z_2 - z_1) \Big/ \left[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2\right]^{1/2}.$$

The third input point is on the major (or minor) axis of the ellipse generated by the intersection of the quadric surface and the plane perpendicular to the line determined by the first two points; furthermore, the third point is on the quadric surface. This point determines the x-axis of the canonical system. The direction cosines of this axis in the vehicle system are determined in the following manner.

The coordinates of the point of intersection (x_4, y_4, z_4) of the canonical z-axis and the plane perpendicular to it and through the third point are given by:

$$x_4 = x_2 + P \cdot \cos\alpha_z$$

$$y_4 = y_2 + P \cdot \cos\beta_z$$

$$z_4 = z_2 + P \cdot \cos\gamma_z$$

where

$$P = (x_3 - x_2)\cos\alpha_z + (y_3 - y_2)\cos\beta_z + (z_3 - z_2)\cos\gamma_z$$

and is the distance from the point (x_2, y_2, z_2) to the point (x_4, y_4, z_4).

The direction cosines of the canonical system x-axis are:

$$\cos \alpha_x = (x_3 - x_4) / \left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]^{1/2},$$

$$\cos \beta_x = (y_3 - y_4) / \left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]^{1/2},$$

$$\cos \gamma_x = (z_3 - z_4) / \left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]^{1/2}.$$

The direction cosines of the y-axis of the canonical system are the direction cosines of the normal to the plane through the three points (x_1, y_1, z_1), (x_2, y_2, z_2), and (x_3, y_3, z_3).

$$T_1 = \begin{vmatrix} 1 & y_1 & z_1 \\ 1 & y_2 & z_2 \\ 1 & y_3 & z_3 \end{vmatrix}$$

$$T_2 = \begin{vmatrix} x_1 & 1 & z_1 \\ x_2 & 1 & z_2 \\ x_3 & 1 & z_3 \end{vmatrix}$$

$$T_3 = \begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix}$$

$$\cos\alpha_y = T_1 / \left[T_1^2 + T_2^2 + T_3^2 \right]^{1/2}$$

$$\cos\beta_y = T_2 / \left[T_1^2 + T_2^2 + T_3^2 \right]^{1/2}$$

$$\cos\gamma_y = T_3 / \left[T_1^2 + T_2^2 + T_3^2 \right]^{1/2}$$

In order to guarantee that the vehicle coordinate and the canonical coordinate systems have the same "handedness", the determinant of the rotation matrix, R, is tested.

$$R = \begin{pmatrix} \cos\alpha_x & \cos\beta_x & \cos\gamma_x \\ \cos\alpha_y & \cos\beta_y & \cos\gamma_y \\ \cos\alpha_z & \cos\beta_z & \cos\gamma_z \end{pmatrix}$$

If the determinant of R is negative, the "handedness" of the two systems is opposite; the proper "handedness" is assured by changing the signs of the canonical system y-axis direction cosines.

For the ellipsoid, the origin of the canonical system is the point (x_4, y_4, z_4), and the canonical coefficients are:

$$A^* = 1 / \left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]$$

$$B^* = 1/b^2$$

$$C^* = 1/c^2$$

$$D^* = 1$$

where b, the second input parameter, is the length of the semi-axis associated

with the canonical y-axis (y_s), and

c, the third input parameter, is the length of the semi-axis associated with the canonical z-axis (z_s). (See Figure 3-2)

For the cylinder, the origin of the canonical system is the point (x_4, y_4, z_4) and the canonical coefficients are:

$$A^* = 1/\left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]$$

$$B^* = 1/b^2$$

$$C^* = 0$$

$$D^* = 1$$

(See Figure 3-3)

For the cone, the origin (x_o, y_o, z_o) of the canonical system is at the vertex of the cone,

$$x_o = x_4 + K\cos\alpha_z$$

$$y_o = y_4 + K\cos\beta_z$$

$$z_o = z_4 + K\cos\gamma_z$$

where $K = \left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]^{1/2} / M$

M is the tangent of the cone half angle associated with the third input point, (x_3, y_3, z_3), and is equal to a/d. (See Figure 3-4)

The canonical coefficients of the cone are:

$$A^* = 1/\left[(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2 \right]$$

$$B^* = 1/b^2$$

$$C^* = -1/K^2$$

$$D^* = 0$$

The transformation from the vehicle system to the canonical system will be, in general, a translation followed by a rotation. This transformation is given by:

$$\begin{pmatrix} x_s \\ y_s \\ z_s \end{pmatrix} = \begin{pmatrix} \cos\alpha_x & \cos\beta_x & \cos\gamma_x \\ \cos\alpha_y & \cos\beta_y & \cos\gamma_y \\ \cos\alpha_z & \cos\beta_z & \cos\gamma_z \end{pmatrix} \begin{pmatrix} x_v - x_o \\ y_v - y_o \\ z_v - z_o \end{pmatrix} \qquad (3\text{-}3)$$

x_v, y_v, and z_v are the coordinate values in the vehicle system; and x_o, y_o, and z_o are the coordinates of the canonical system origin in terms of the vehicle system.

Substituting Equations 3-3 in Equation 3-4

$$A^* x_s^2 + B^* y_s^2 + C^* z_s^2 = D^* \qquad (3\text{-}4)$$

leads to the coefficients of the quadric surface in the vehicle coordinate system.

$$A = A^* \cdot \cos^2\alpha_x + B^* \cdot \cos^2\alpha_y + C^* \cdot \cos^2\alpha_z$$

$$B = A^* \cdot \cos^2\beta_x + B^* \cdot \cos^2\beta_y + C^* \cdot \cos^2\beta_z$$

$$C = A^* \cdot \cos^2\gamma_x + B^* \cdot \cos^2\gamma_y + C^* \cdot \cos^2\gamma_z$$

$$D = 2 \cdot (A^* \cdot \cos\alpha_x \cdot \cos\beta_x + B^* \cdot \cos\alpha_y \cdot \cos\beta_y + C^* \cdot \cos\alpha_z \cdot \cos\beta_z)$$

$$E = 2 \cdot (A^* \cdot \cos\alpha_x \cdot \cos\gamma_x + B^* \cdot \cos\alpha_y \cdot \cos\gamma_y + C^* \cdot \cos\alpha_z \cdot \cos\gamma_z)$$

$$F = 2 \cdot (A^* \cdot \cos\beta_x \cdot \cos\gamma_x + B^* \cdot \cos\beta_y \cdot \cos\gamma_y + C^* \cdot \cos\beta_z \cdot \cos\gamma_z)$$

$$G = -(y_o \cdot D + z_o \cdot E + 2 \cdot x_o \cdot A)$$

$$H = -(x_o \cdot D + z_o \cdot F + 2 \cdot y_o \cdot B)$$

$$P = -(x_o \cdot E + y_o \cdot F + 2 \cdot z_o \cdot C)$$

$$Q = A \cdot x_o^2 + B \cdot y_o^2 + C \cdot z_o^2 + D \cdot x_o \cdot y_o + E \cdot x_o \cdot z_o + F \cdot y_o \cdot z_o - D^*$$

The signs of the coefficients are determined so that an internal point, (x, y, z), of the volume will cause the expression

$$Ax^2 + By^2 + Cz^2 + Dxy + Exz + Fyz + Gx + Hy + Pz + Q$$

to be positive.

The parameters required for generating surface coefficients do not necessarily have to be obtained in the vehicle coordinate system. These parameters may be obtained in any convenient coordinate system and then moved to the vehicle coordinate system with a user-specified transformation. The transformation operates on the three points defining each surface and on the internal point for the volume element. It continues to move volume elements until a new transformation is input or a signal is given to ignore the transformation (see NTRNS, Section 3.5).

The transformation from the convenient coordinate system to the vehicle coordinate system consists of a rotation plus a translation. This transformation may be constructed in the following manner.

Let X^1, Y^1, and Z^1 denote the coordinate axes of the convenient system. In the vehicle coordinate system, the direction cosines of the X^1-axis are $\alpha_x 1$, $\beta_x 1$, and $\gamma_x 1$ - and similarly for the Y^1 and Z^1 coordinate axes. Having determined the direction cosines, the rotation matrix, R, may be written:

$$R = \begin{pmatrix} \alpha_x 1 & \alpha_y 1 & \alpha_z 1 \\ \beta_x 1 & \beta_y 1 & \beta_z 1 \\ \gamma_x 1 & \gamma_y 1 & \gamma_z 1 \end{pmatrix} \qquad (3\text{-}5)$$

The translation vector, T, is given by the vehicle system coordinates, (X, Y, Z), of the origin of the convenient coordinate system.

$$T = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad (3\text{-}6)$$

The complete transformation is given by:

$$\begin{pmatrix} X_v \\ Y_v \\ Z_v \end{pmatrix} = R \cdot \begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix} + T \qquad (3\text{-}7)$$

where the point (X_c, Y_c, Z_c) in the convenient system is transformed to (X_v, Y_v, Z_v) in the vehicle system.

The elements of the rotation matrix, R, in Equation 3-5 correspond to the entries in the data array, ARY, listed in Section 3.5.

$$ARY(1) = \alpha_{x1}$$

$$ARY(2) = \alpha_{y1}$$

$$ARY(3) = \alpha_{z1}$$

$$ARY(4) = \beta_{x1}$$

. . . . . .

$$ARY(9) = \gamma_{z1}$$

The elements of the translation vector T, Equation 3-6, correspond to the data names TX, TY, and TZ respectively, listed in Section 3.5.

The boundaries of a volume element may be defined in two ways, directly or indirectly. The direct way defines all surfaces that are boundaries of the volume element. The indirect way, termed "embedding", employs the boundaries of previously defined volume elements. The embedding feature is illustrated in Figure 3-5. The first example exhibits complete embedding where a volume element is enclosed by another. The second example shows partial embedding where a partial overlap takes place. In both examples it is necessary to specify only the outside surfaces of each volume element plus internal points, densities, and material numbers. A maximum of 25 volume elements may compete for a spatial region. Dominance is assigned by order of data input: each volume element takes precedence over all volume elements which follow in the data deck.

In some instances the embedding feature significantly reduces data preparation time and machine time. For example, the four triple-walled mission modules described in Section 2.1 require 48 volume elements and 148 surfaces without embedding. Using the embedding feature, only 16 volume elements and 32 surfaces are necessary. A further advantage is that components may be added to an already existing configuration without changing previous data.

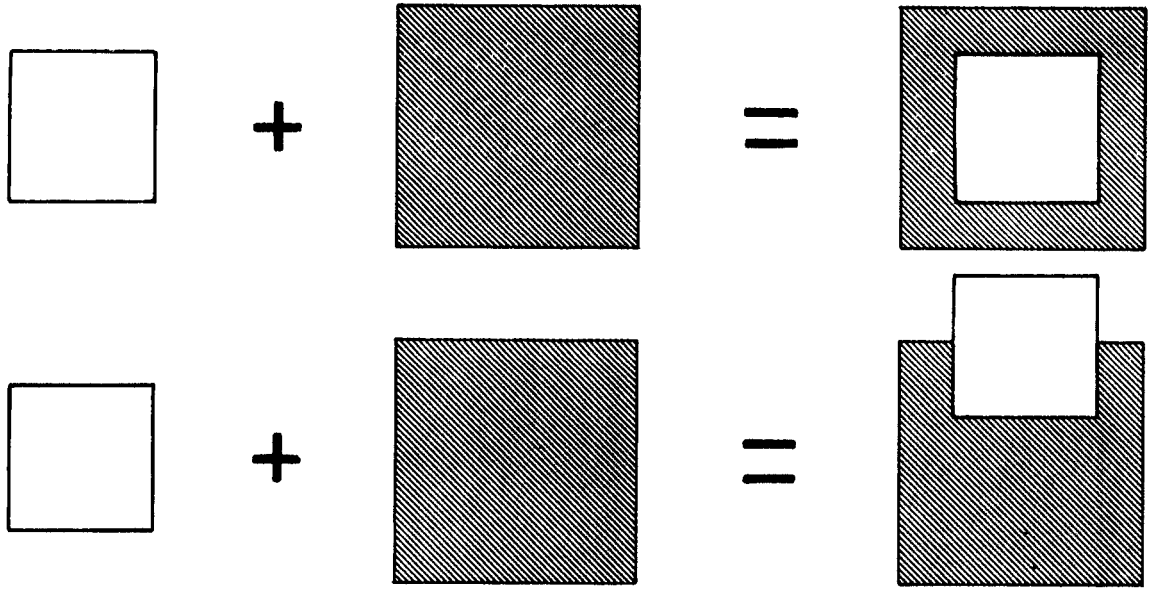


FIGURE 3-5 VOLUME ELEMENT EMBEDDING

3.2 VECTOR GENERATION

The geometric configuration is scanned by the Geometry Program in the following way. An axially symmetric figure is generated by rotating line segments about the z-axis. A rotated line segment generates a truncated conical or cylindrical shell. Each shell is approximated by six equal planar facets. A portion of this polyhedral envelope is illustrated in Figure 3-6. It is determined by an input data set consisting of z-coordinate values, z_i, and radius values, r_i (ZZ and RR in Section 3.5). The coordinates of the vertices of the facets of the polyhedral envelope are obtained from the relations

$$\begin{aligned} x_{m,i} &= r_i \cos\frac{m\pi}{3} && m = 1, 2, \ldots 6 \\ y_{m,i} &= r_i \sin\frac{m\pi}{3} && m = 1, 2, \ldots 6 \\ z_{m,i} &= z_i && m = 1, 2, \ldots 6 \end{aligned} \qquad (3\text{-}8)$$

If an r_i is zero, the associated facets are triangular with $(0, 0, z_i)$ as a common vertex for the six triangles whose remaining vertices are determined by (3-8) with i equal to $j + 1$ or $j - 1$. However, reentrant surfaces are not permitted on the polyhedral envelope; therefore, only the first and/or the last r_i may have zero value. If r_i and r_{i+1} are not zero, the associated facets are trapezoidal.

Each facet is subdivided into regions until the solid angle subtended by each region at a detector is less than the input solid angle criterion for that facet. This feature permits critical shield areas to be examined closely.

Facets are divided into triangular and trapezoidal regions. In order to reduce code operating time, the approximate solid angle associated with a region is computed and compared to the criterion. The approximate solid angle is:

$$\Omega \cong \frac{A \cdot \cos\theta}{r^2} ,$$

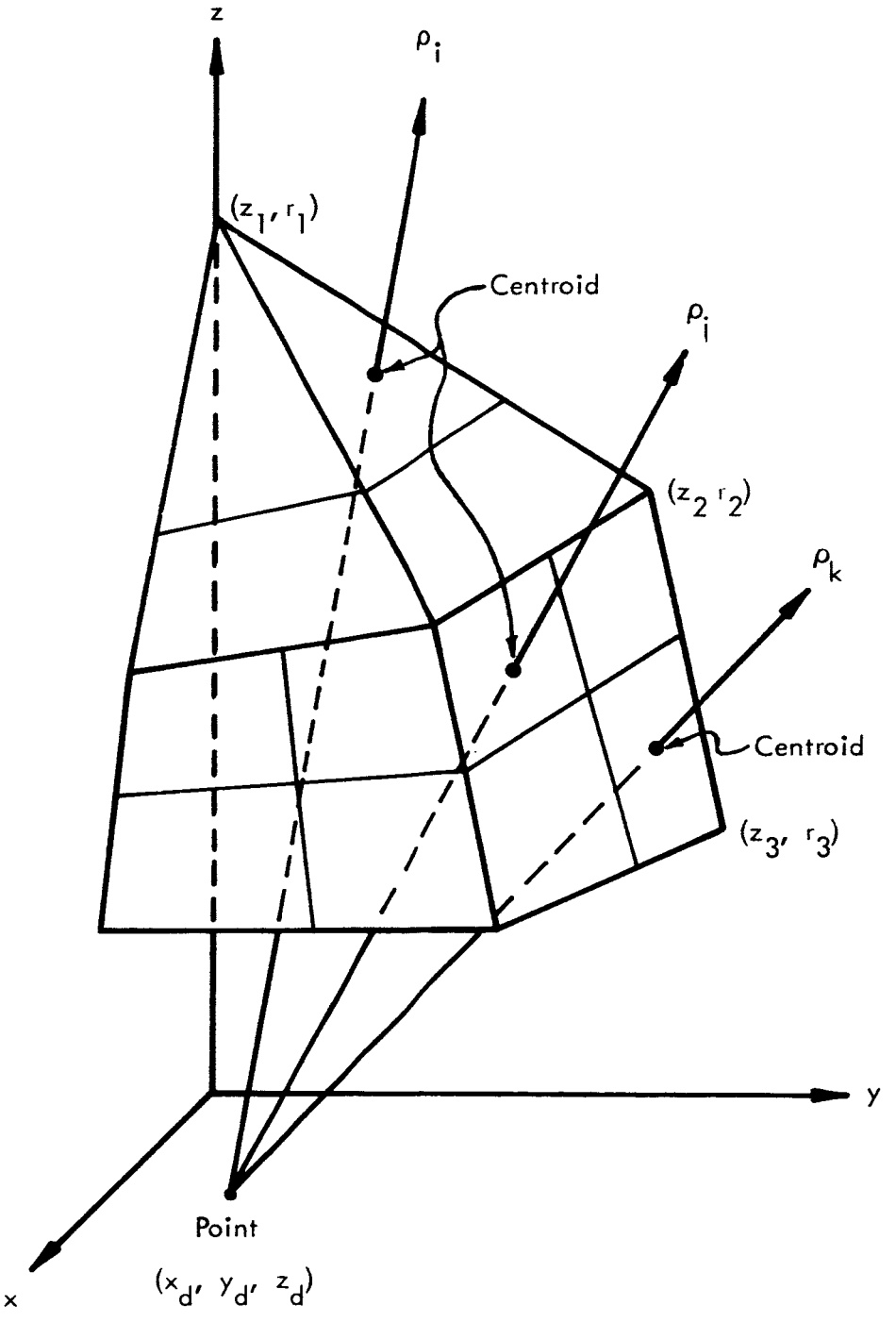


FIGURE 3-6 POLYHEDRAL ENVELOPE

where A = area of the region,

θ = angle between the vector and the normal to the facet, and

r = distance between the detector and the centroid of the region.

When the approximate solid angle is less than the solid angle criterion, the exact solid angle is computed, by projecting the region onto the unit sphere, and compared to the criterion. Further division may occur if the criterion is exceeded.

A vector array associated with each detector is then generated. Each vector joins the detector to the centroid of a region. The direction cosines of the vector, ρ, from the detector are computed using the coordinates of the centroid (x_c, y_c, z_c) and the coordinates of the detector (x_d, y_d, z_d).

$$\cos \alpha_\rho = (x_c - x_d) \Big/ \left[(x_c - x_d)^2 + (y_c - y_d)^2 + (z_c - z_d)^2 \right]^{1/2}$$

$$\cos \beta_\rho = (y_c - y_d) \Big/ \left[(x_c - x_d)^2 + (y_c - y_d)^2 + (z_c - z_d)^2 \right]^{1/2}$$

$$\cos \gamma_\rho = (z_c - z_d) \Big/ \left[(x_c - x_d)^2 + (y_c - y_d)^2 + (z_c - z_d)^2 \right]^{1/2}$$

A different polyhedral envelope may be generated for each detector. The solid angle criteria (SAC of Section 3.5) may also be changed for each detector. It should be noted that the polyhedral envelope is used to generate the vector array; it need have no relationship with the geometric configuration.

3.3 PENETRATION LENGTHS

Having generated a vector, those segments of the vector which lie inside volume elements are calculated. Each vector associated with a detector is processed until the entire polyhedral envelope has been scanned. This procedure is continued for

all detectors.

The distance, ρ, from a detector (x_d, y_d, z_d) to any surface in the direction of the vector may be obtained by substituting Equations 3-9 into the expression for the surface and solving for ρ.

$$\begin{aligned} x_i &= x_d + \rho \cdot \cos\alpha_\rho \\ y_i &= y_d + \rho \cdot \cos\beta_\rho \\ z_i &= z_d + \rho \cdot \cos\gamma_\rho \end{aligned} \tag{3-9}$$

The point (x_i, y_i, z_i) is on the surface and, therefore, the expression will be zero for that point.

For the plane,

$$\rho = \frac{D - A \cdot x_d - B \cdot y_d - C \cdot z_d}{A \cdot \cos\alpha_\rho + B \cdot \cos\beta_\rho + C \cdot \cos\gamma_\rho}$$

provided the denominator is not zero; in this case, the vector is parallel to or in the plane. For the purposes of this program, this condition is regarded as no intercept with the plane surface.

The calculation of the distance to intercept on a quadric surface is considerably more tedious.

$$\rho = \frac{-U \pm \left[U^2 - 4 \cdot V \cdot W\right]^{1/2}}{2 \cdot V}$$

where

$$V = A \cdot \cos^2\alpha_\rho + B \cdot \cos^2\beta_\rho + C \cdot \cos^2\gamma_\rho + D \cdot \cos\alpha_\rho \cdot \cos\beta_\rho + E \cdot \cos\alpha_\rho \cdot \cos\gamma_\rho + F \cdot \cos\beta_\rho \cdot \cos\gamma_\rho$$

$$U = 2 \cdot (A \cdot x_d \cdot \cos\alpha_\rho + B \cdot y_d \cdot \cos\beta_\rho + C \cdot z_d \cdot \cos\gamma_\rho) + D \cdot (y_d \cdot \cos\alpha_\rho + x_d \cdot \cos\beta_\rho) + E \cdot (z_d \cdot \cos\alpha_\rho + x_d \cdot \cos\gamma_\rho) + F \cdot (z_d \cdot \cos\beta_\rho + y_d \cdot \cos\gamma_\rho) + G \cdot \cos\alpha_\rho + H \cdot \cos\beta_\rho + P \cdot \cos\gamma_\rho$$

$$W = A \cdot x_d^2 + B \cdot y_d^2 + C \cdot z_d^2 + D \cdot x_d \cdot y_d + E \cdot x_d \cdot z_d + F \cdot y_d \cdot z_d + G \cdot x_d + H \cdot y_d + P \cdot z_d + Q$$

If V is zero, which may be the case in certain circumstances with the cone, then

$$\rho = -W/U$$

For each vector, a table of real non-negative ρ's is computed. Because the detector may be inside the volume element, the detector is taken to be the first intercept, that is, $\rho_1 = 0$. Having obtained a table of ρ's for a given vector, the table is ordered by increasing magnitude.

The mid-points (x_m, y_m, z_m) between consecutive pairs of ρ_i's are calculated using Equations 3-10.

$$x_m = x_d + \frac{1}{2}(\rho_i + \rho_{i+1}) \cos\alpha_\rho$$
$$y_m = y_d + \frac{1}{2}(\rho_i + \rho_{i+1}) \cos\beta_\rho \qquad (3\text{-}10)$$

$$z_m = z_d + \frac{1}{2}(\rho_i + \rho_{i+1}) \cos\gamma_\rho$$

The distance from the mid-point to each of the planes associated with the volume element in the direction of the normal to the plane is computed by Equation 3-11.

$$d_i = D_i - A_i \cdot x_m - B_i \cdot y_m - C_i \cdot z_m \qquad (3\text{-}11)$$

If any d_i is negative, the midpoint is not inside the volume element. If all d_i's are non-negative, the relationship of the mid-point with all quadric surfaces associated with the volume element is investigated by substituting the coordinates of the mid-point into Equation 3-12.

$$q_i = A_i \cdot x_m^2 + B_i \cdot y_m^2 + C_i \cdot z_m^2 + D_i \cdot x_m \cdot y_m + E_i \cdot x_m \cdot z_m + F_i \cdot y_m \cdot z_m + G_i \cdot x_m + H_i \cdot y_m + P_i \cdot z_m + Q_i \qquad (3\text{-}12)$$

If any q_i is negative, the mid-point is not inside the volume element. If all q_i's are non-negative, the mid-point is inside the volume element. A mid-point inside a volume element implies that the segment of the vector between the two intercepts defining the mid-point is also inside the volume element. The length of the segment is $\rho_{i+1} - \rho_i$. All mid-points generated by the ρ-table are processed, obtaining all non-zero length segments of the vector which lie inside the volume element. After all volume elements have been processed for a given vector, the segments are ordered by distance from the detector point.

3.4 GEOMETRY PROGRAM LIMITATIONS

Many of the working parameters are packed sequentially into tables or loaded into a single word to conserve core storage. The number of volume elements is limited to 1000 by the dimensions on NX, the number of planar surfaces bounding volume

elements; NXQ, the number of quadric surfaces; and MVX, the material number. These 3000 values are compressed into 1000 storage locations labeled NSUR (I). Machine time is increased less than one percent by packing and unpacking these parameters. The number of volume elements permitted may be further restricted by available surface coefficient storage. Sixteen thousand locations are reserved for these coefficients which are stored in one data array. The restriction is:

$$4 \cdot P + 10 \cdot Q \leqq 16,000$$

where P is the total number of planes in the configuration and
Q is the total number of quadric surfaces. The maximum number of surfaces which may directly bound a volume element is 25.

The maximum number of surfaces bounding a volume element may be indirectly increased with embedding. No region of space may be included within more than 25 volume elements.

In connection with vector generation from a detector to the facets of the polyhedral envelope, the maximum number of facets is 120. Therefore, a maximum of 120 solid angle criteria (SAC) and 21 Z-coordinate values (ZZ) defining the polyhedron may be specified. Each facet may be subdivided automatically if the solid angle criterion is exceeded.

The maximum number of vectors which may be associated with a detector exceeds 49,152 for a twelve-faceted polyhedron and exceeds 491,520 for a one hundred twenty-faceted polyhedron. The maximum may be considerably larger, depending on the manner in which facets are subdivided. The number of detectors associated with a configuration is unlimited. The only restriction on detector location is that it be within its polyhedral envelope; otherwise, less than 4 pi steradians will be examined. The solid angle examined by the vector array is equal to the solid angle

subtended by the polyhedral envelope from the detector. No straight line should penetrate the polyhedron in more than two points; i.e., no reentrant boundaries.

The maximum number of penetration thicknesses which may be computed for a single vector is 50.

3.5 GEOMETRY PROGRAM DATA INPUT PREPARATION

In the following, the column headed "FORMAT" gives the DIP format control under which this data is to be read, the column headed "NAME" gives the name of the data array, the column headed "DIMENSION" indicates the number of words available in fast storage for the named array, and the column headed "DEFINITION" is a description of the named data array.

The name card for the following data set must be:

N18, NX, NXQ, MVX, RHX, XXI, YYI, ZZI, XX, YX, ZX, KQ, RA, PR, ARY, TX, TY, TZ, NTRNS

(See description of the DIP program - Appendix A.1.)

FORMAT	NAME	DIMENSION	DEFINITION
4	NX	(1)	The number of planar surfaces bounding the volume element.
4	NXQ	(1)	The number of quadric surfaces bounding the volume element.
4	MVX	(1)	Material number assigned to the volume element. A value of zero indicates the last

FORMAT	NAME	DIMENSION	DEFINITION
4	MVX (Continued)	(1)	volume element has been processed and control passes to the vector generation section of the program.
3	RHX	(1)	"Density" associated with the volume element. This value may also involve conversion factors as well as density. For example, if the linear unit of the input data is the inch, then RHX is density (gm/cm^3) times 2.54 (cm/inch) to convert penetration thicknesses to gm/cm^2.
3	XXI	(1)	The coordinates of a point which lies within the volume element. This point MUST NOT lie on any of the surfaces that bound the volume element.
3	YYI	(1)	
3	ZZI	(1)	
3	XX	(3, 25)	The coordinates of three SPECIAL points. Each set of three points define a bounding surface of the volume element (the quadric surfaces require some additional parameters). The points defining the planar surfaces of the volume element MUST be input BEFORE the points defining the quadric surfaces of the volume element. The set of three points needed to define the various surfaces are as follows:
3	YY	(3, 25)	
3	ZZ	(3, 25)	

- planar surface - three non-collinear points

FORMAT	NAME	DIMENSION	DEFINITION
			• planar surface (continued) in the planar surface.
			• ellipsoidal surface - the first two points must be on a semi-axis (or its extension), and the third point must be on another semi-axis AND the surface.
			• elliptic cylindrical surface - the first two points must be on the axis of the cylinder, and the third point must be on a semi-axis of an ellipse of cross-section AND on the surface.
			• elliptic conical surface - the first two points must be on the axis of the cone (the direction from P_1 to P_2 must indicate the direction of the nappe of interest, here direction of the nappe is assumed to point toward the vertex), the third point must be on a semi-axis of the ellipse of cross-section and on the surface.
4	KQ	(25)	A parameter associated with each type of quadric surface: 1 - ellipsoidal surface, 2 - elliptic cylindrical surface, 3 - elliptic conical surface.

FORMAT	NAME	DIMENSION	DEFINITION
3	RA	(25)	A parameter associated with each quadric surface. The length of a semi-axis of the ellipse of cross-section (must not be the semi-axis associated with the third point or the first two in the case of an ellipsoid).
3	PR	(25)	A parameter associated with ellipsoids and cones: • ellipsoid, the length of the semi-axis associated with the first two points, • cone, the tangent of the cone half-angle determined by the semi-axis associated with the third point.
4	NTRNS	(1)	A transformation signal: • $\leq$ 0, no transformation to be performed on the volume element; • > 0, a transformation will be performed on the volume element.
3	ARY	(9)	The matrix elements of the rotation desired for the volume element. (See Equation 3-5)
3	TX	(1)	The vector elements of the translation desired for the volume element. (See Equation 3-6)
3	TY	(1)	
3	TZ	(1)	

Control must be returned to the main program following the data defining each volume element.

The above data names refer to the volume elements and their associated surfaces. It is this data that determines the geometric configuration.

The following data names refer to vector generation, detector location, and some miscellaneous information. These data follow volume element data in the input deck.

The name card for the following data set must be:

N12, NZ, ZZ, RR, XD, YD, ZD, ND, N2, DHED, MD, BIN, SAC

(See description of the DIP program - Appendix A.1.)

FORMAT	NAME	DIMENSION	DEFINITION
3	NZ	(1)	The number of line segments to be used in generating the polyhedral envelope. (See Section 3.2)
3	ZZ	(21)	The Z-coordinate values that define the line segments. There should be (NZ + 1) values of ZZ. (See Section 3.2)
3	RR	(21)	The radius values (distance from Z-axis) that define the line segments. The first and last RR values must be zero. The total number of RR values must equal (NZ + 1). (See Section 3.2)

FORMAT	NAME	DIMENSION	DEFINITION
3	XD	(1)	The coordinates of the detector location in the geometric configuration.
3	YD	(1)	
3	ZD	(1)	
4	ND	(1)	A processing signal: • < 0, processing of the configuration and detector locations is to be ended. An end-of-file is written on the geometry tape. • ≥ 0, process the current detector location.
4	N2	(1)	The geometry tape assignment; that is, the logical number of the tape unit upon which the geometry output data (for the Dose Code) is to be written.
5	DHED	(10)	Heading information associated with the current detector. This information will be put on the geometry tape for use by the Dose Code.
4	MD	(1)	The detector material number associated with the current detector. This number will be used in the dose code to determine the parameters needed to calculate the stopping power.

FORMAT	NAME	DIMENSION	DEFINITION
5	BIN	(1)	Hollerith information indicating the storage location of the geometry data tape (written on N2) that will be used by the dose code.
3	SAC	(1)	The solid angle criteria associated with the detector currently under consideration. There are 6 times NZ criteria for each detector; that is, there is a solid angle criterion associated with the detector for each facet of the polyhedron.

Control must be returned to the main program following each set of detector data. Sample input data are listed in Appendix A.2.

3.6 GEOMETRY PROGRAM OUTPUT

The Geometry Program generates two sets of output; a BCD tape for off-line listing and a binary tape for use by the Dose Program. The BCD output consists of some general information regarding the geometric configuration and the detectors. The total number of volume elements is given. For each detector, Hollerith identification, detector number, number of vectors, total solid angle, detector material number, and detector coordinates are given. A table labeled MATERIAL NUMBERS AND DENSITIES contains these parameters for each volume element. The last line indicates the user-specified storage bin of the binary output tape.

The binary output tape contains a data block for the detector, followed by a data block for each vector associated with that detector. The sequence is repeated for each detector.

The detector block contains detector coordinates, detector material number, and Hollerith identification. The vector data block contains vector solid angle, direction cosines, the number of penetration thicknesses, the penetration thickness table (50 entries), and the material number table associated with the penetration thicknesses (50 entries). After all vectors associated with a detector have been treated, a final vector data block is written with the number of penetration thicknesses set to minus one. This flag signals the DoseCode to proceed to the next detector. When the last detector has been processed, an "end-of-file" is written on the tape.

4.0 GEOMETRY TEST PROGRAM

The purpose of the Geometry Test Program is to provide assistance in determining the validity of the geometric input data. This test proceeds in two phases. First, the input data is checked for format, acceptable characters, and inconsistencies. Second, cross sectional plots are generated to provide visual confirmation of the configuration. This test program is essentially the Geometry Program with different output.

4.1 INPUT DATA CHECK

The Geometry Test Program processes the same data used by the Geometry Program to generate the configuration. Errors in format and improper characters are detected during data input. If an error is detected, processing does not cease; the remaining data are scanned by the DIP input program for any additional errors. The images of all cards which DIP interprets as containing errors are printed off-line and processing stops. If a listed card contains no error, a preceding card, listed or unlisted, contains the error which caused this card image to be printed.

A logical inconsistency arises if the internal point is on the surface of a volume element. In this event, a number indicating the sequential location of the volume element data in the data set is printed with an appropriate comment. An error in data defining a surface may result in this type of error indication. The tenth such error halts processing immediately. One to nine such errors causes processing to cease after all volume elements have been generated.

4.2 CONFIGURATION CHECK

Barring any previous errors, the test program produces off-line cross sectional plots specified by the user. The particular region plotted is determined by three points which lie on corners of a parallelogram. The test program generates a set of parallel

vectors in this parallelogram. The direction and magnitude of these vectors are determined by the first two points. The extent of the vector set is determined by the first and third points. The coordinates of these three points are input values specified by the user. The segments of each vector which lie within volume elements are determined by the same method used in the Geometry Program. A unique character is assigned to each volume element encountered. Volume elements with zero density are not assigned characters.

A table of character assignments associated with a plot is printed when the plot has been completed. In the event that the character assignment capacity is exceeded - 43 characters are available - the plotting is interrupted and the character assignment table is printed. The plotting process resumes with the last vector treated and the characters are reassigned. Sample output plots are shown in Figures 4-1 and 4-2.

4.3 GEOMETRY TEST PROGRAM DATA INPUT PREPARATION

The Geometry Test Program is designed to test the data input to the Geometry Program in order to verify that the data has been properly prepared and that the configuration desired has actually been generated. Therefore, all data input to the Geometry Program which is required to define the volume elements that constitute the geometric configuration is also data input to the Geometry Test Program. The data input to the Geometry Program that refer to vector generation, detector location, and some miscellaneous information is NOT input to the Geometry Test Program.

The Geometry Test Program requires some additional information to determine the cross-sectional plots the user desires to make of the configuration. The following describes this additional data.

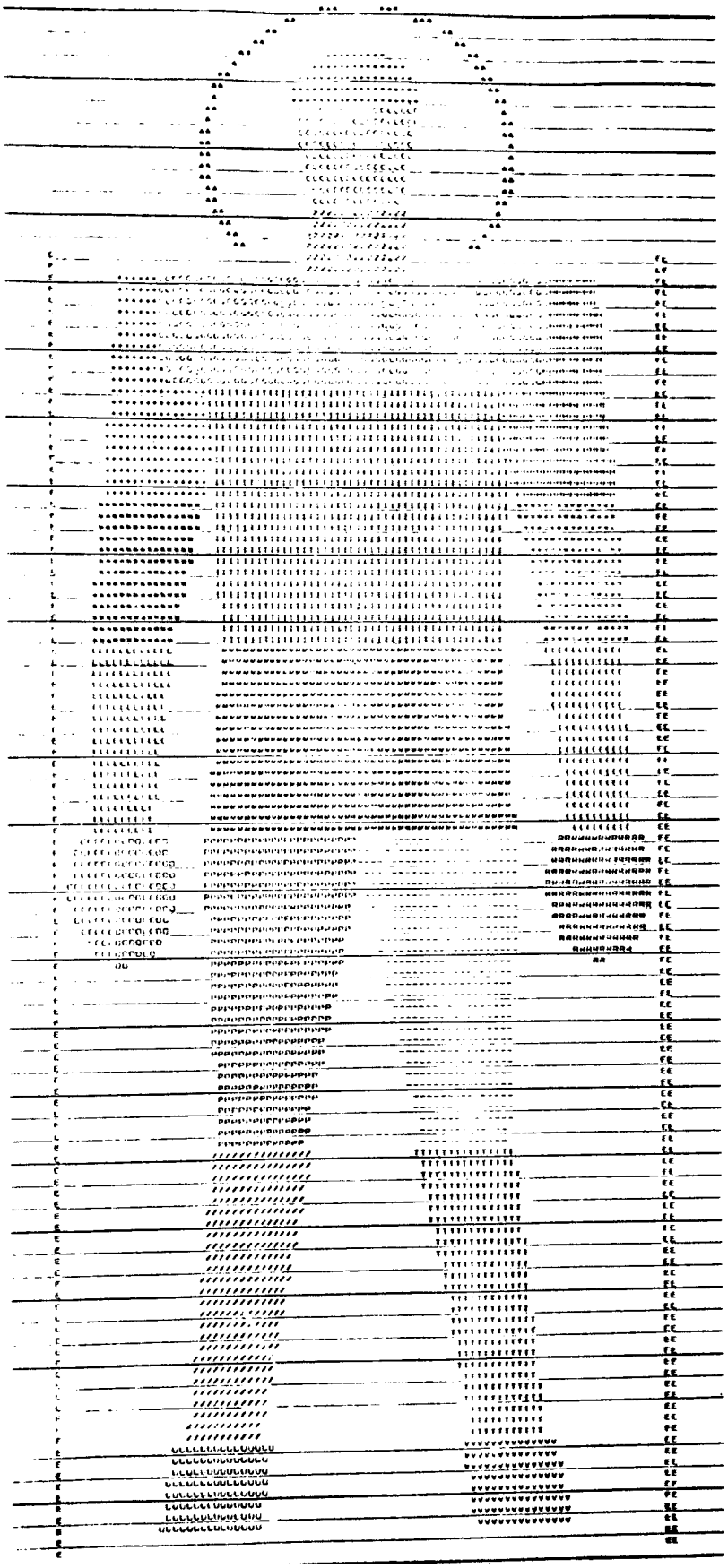


FIGURE 4-1 MAN MODEL IN SIMULATED SPACE SUIT

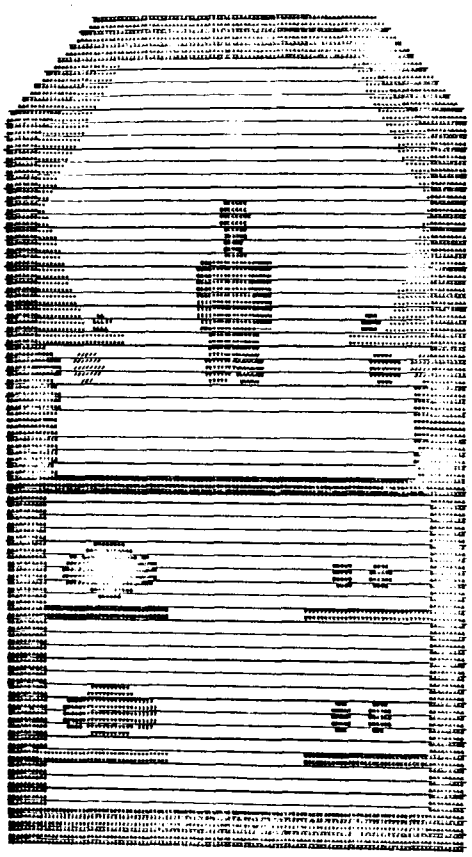


FIGURE 4-2 EIGHT MAN MODULE VERTICAL SECTION

The name card for the following data set which follows volume element data, must be:

N11, XX, YX, ZX, NH, NV, KIND, NTRNS, ARY, TX, TY, TZ

(See description of the DIP Program - Appendix A.1.

FORMAT	NAME	DIMENSION	DEFINITION
3	XX	(3)	The coordinates of three points which define the plane of cross-section and the extent of the cross-section. The first two points input determine the "horizontal" extent of the cross-section; that is, line segments parallel to a line through the first two points will be printed across the page of printed output, and only those volume elements which are penetrated by these line segments will be indicated. The first and third points determine the extent of the parallel set of line segments.
3	YX	(3)	
3	ZX	(3)	

NOTE: If the three points do not lie on the corners of a rectangle, a shear distortion will result due to the mapping of a parallelogram onto a rectangle.

4	NH	(1)	The number of character spaces to be assigned to each parallel line segment. This must not have a value greater than 131. An NH with a zero or negative value terminates the computation.

FORMAT	NAME	DIMENSION	DEFINITION
4	NV	(1)	The number of parallel line segments to be generated between the first and third points. This must not have a value greater than 500.

NOTE: A stretch distortion may be introduced if NV does not have the proper value in relation to NH and the three points. However, if NV is zero or negative the program will compute the proper value of NV for a six-lines-per-inch printer.

5	KIND	(10)	Hollerith information to identify the particular cross-section of current interest.
4	NTRNS	(1)	A transformation signal: • $\leq$ 0, no transformation to be performed on the cross-sectional plane; • > 0, a transformation will be performed on the cross-sectional plane.
3	ARY	(9)	The matrix elements of the rotation desired for the cross-sectional plane.
3	TX	(1)	The vector elements of the translation desired for the cross-sectional plane.
3	TY	(1)	
3	TZ	(1)	

Control must be returned to the program following data for each plot. Sample input data are listed in Appendix A.2.

4.4 GEOMETRY TEST PROGRAM OUTPUT

Format errors and improper characters in the input data cause the erroneous card or a following card to be printed with an error comment. An internal point on a surface and certain types of surface data errors cause an error print identifying the volume element. Plots are printed with a heading specified by the user. A character assignment table follows each plot. The first line repeats the heading identifying the plot. The table lists characters assigned, material numbers, densities, and the sequential number of the volume element in the input data. The "density" values are the quantities RHX described in Section 3.5.

5.0 DOSE PROGRAM

The Dose Program calculates primary proton and related secondary dose (or dose rate) at points in a geometric configuration. This program obtains the geometric data from a tape generated by the Geometry Program. The flux data, range parameters for the materials involved, and other data applicable to the various materials in the configuration are input directly. Thus, the Geometry Program does not have to be rerun to study the effect of material changes, including changes in material density. Further, the Dose Program may calculate the dose (or dose rate) in specified angular regions; these angular regions are determined by their polar and azimuthal bounds.

The Dose Program approximates the appropriate proton spectrum, differential in energy, with from one to one hundred power law representations over the energy range of interest. The source and geometric data are applied to an attenuation method suggested in a NASA Technical Memorandum by M. O. Burrell[1]. This suggestion allows treatment of multilayer shields of diverse materials by analytical techniques.

The validity of these techniques has been tested by comparing the results of the Dose Program to those of the Lockheed Proton Penetration Code (LPPC)[2] in spherical shell shield geometry for isotropic flux. Several spectra, materials, and material combinations have been examined. Comparisons for aluminum, iron, and water are shown in Figures 5-1 through 5-3. For various combinations of aluminum, polyethylene, iron, and tissue, the Dose Program differed from LPPC by only two percent at most. The method appears to be satisfactory for shields less than 100 grams per square centimeter thick; investigations of thicker shields have not been conducted. Thin shield tests have been conducted to .004 gms/cm^2 of aluminum and reasonable values have resulted. Unshielded dose calculations have also compared extremely well with LPPC.

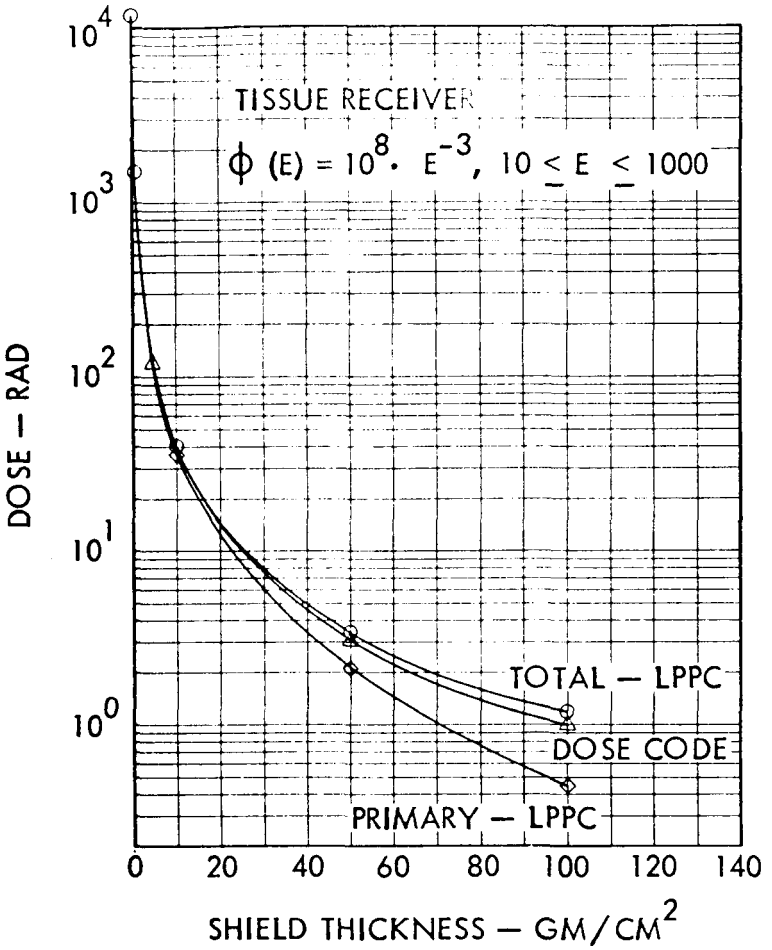


FIGURE 5-1 SPHERICAL SHIELD ALUMINUM

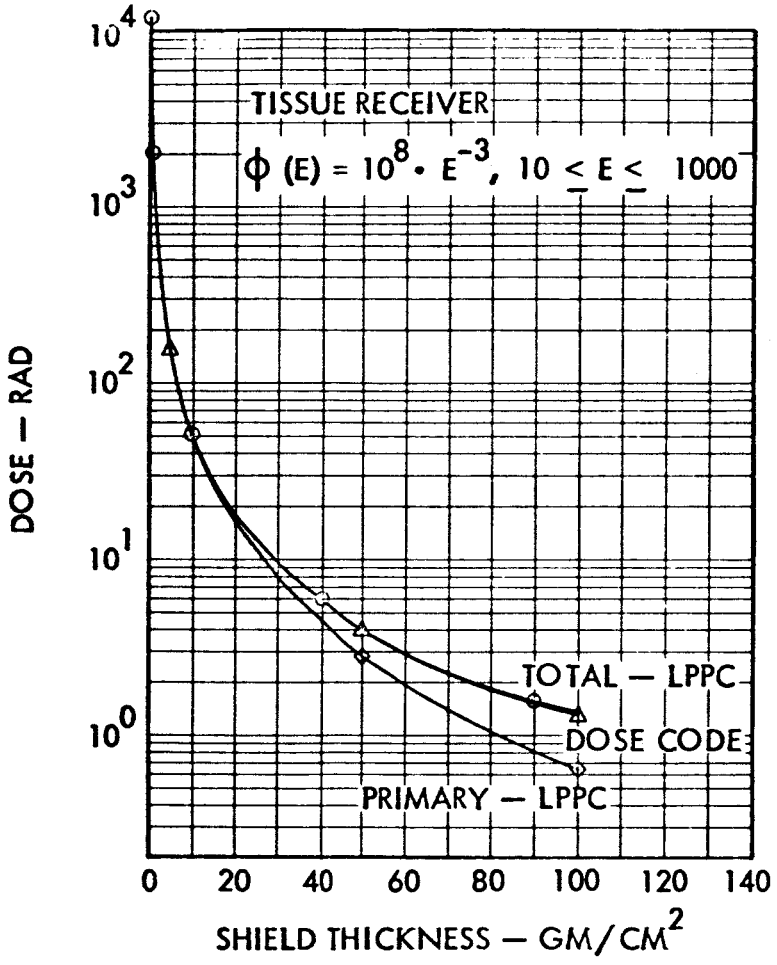


FIGURE 5-2 SPHERICAL SHIELD IRON

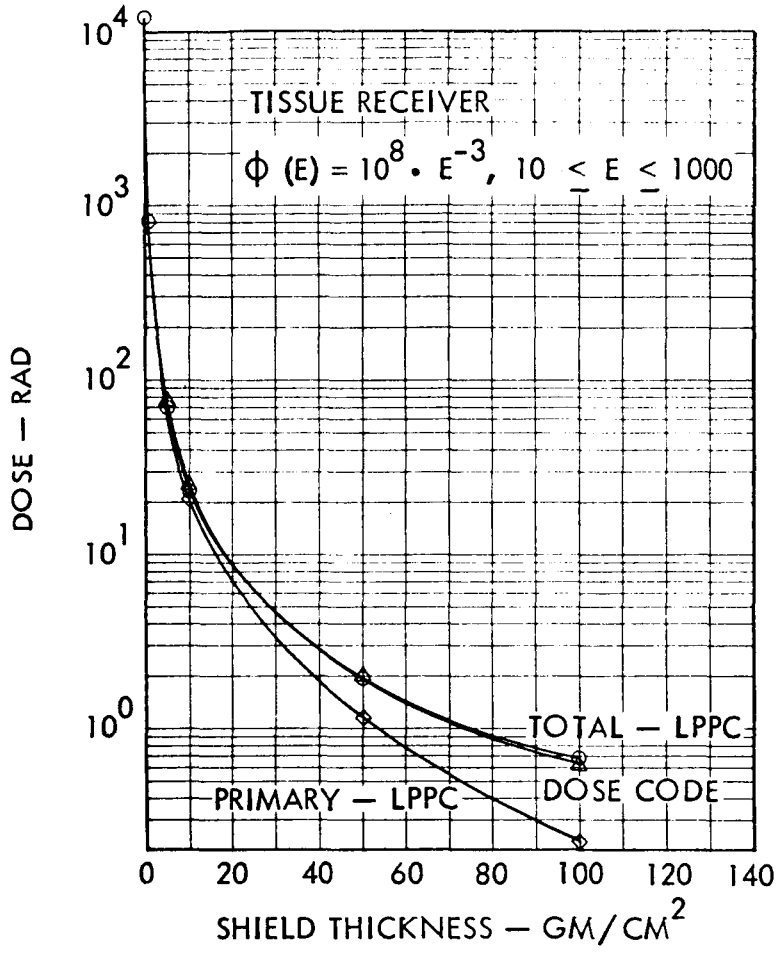


FIGURE 5-3 SPHERICAL SHIELD WATER

5.1 RADIATION TRANSPORT

An expression of the physical dose or dose rate at a detector is given by Equation 5-1.

$$D_i = K \sum_{i=1}^{N} \Omega_{ij} \int_0^{\infty} B(X_{ij}, E) \cdot P(X_{ij}, E) \cdot S_i(E) \, dE \qquad (5\text{-}1)$$

Where D_i = dose (rad) or dose rate at the i^{th} detector

K = flux-to-dose conversion factor

Ω_{ij} = i^{th} solid angle of the j^{th} detector

X_{ij} = penetration lengths (gm/cm^2) through all materials in i^{th} solid angle of the j^{th} detector

$B(X_{ij}, E)$ = correction factor to account for nuclear collision losses of primary protons with energy E and the production and attenuation of secondary radiations

$P(X_{ij}, E)$ = proton flux, differential in energy, arriving within the i^{th} solid angle of the j^{th} detector.

$S_i(E)$ = proton stopping power in the i^{th} detector material

Each of these factors are discussed in turn. The approximations required for computational purposes are illustrated and the transport equations used in the code are detailed.

The basic dose unit is chosen to be the rad. A physical dose, D_i, is calculated rather than a biological dose because information on RBE for the radiations of interest is rather sparse. The use of physical dose units also permits components other than biological specimens to be treated, e.g., photographic emulsion and semiconductors.

The flux-to-dose conversion factor, K, converts energy deposition in the detector to dose units. For example, if the units of stopping power are MeV-cm^2/gm and the units of time-integrated proton flux are p/cm^2-MeV-ster, the value of K is 1.602×10^{-8} rad-gm/MeV. If proton flux is given as p/cm^2-sec-MeV-ster, the dose rate may be computed in terms of rad/hr with K equal to 5.76×10^{-5} rad-gm-sec/MeV-hr.

The quantity, Ω_{ij}, represents an incremental solid angle about a vector emanating from the detector. The vector possesses direction cosines α, β, and γ. The maximum size of Ω_{ij} is specified by input data to the Geometry Program. Generally, a maximum of 0.2 steradians, generating approximately 100 incremental solid angles, has proved satisfactory. The number of increments was varied from 100 to 1000 for several detectors in the cases treated in Section 2. The variation in dose was less than four per cent except in one instance where it reached seven per cent.

The quantity X_{ij} in Equation 5-1 represents shield penetration lengths along the vector in Ω_{ij}. The representation is symbolic. Actually, the code treats radiation transport through each layer in sequence in a multi-material shield configuration, starting at the outside and going to the detector.

The radiation transport method used in Equation 5-1 makes no explicit reference to the generation and attenuation of secondary radiations, nor to the attenuation of primary protons due to nuclear collisions. To some extent the lack of generating secondary nucleons compensates the lack of attenuation of the primary protons by nuclear collisions which generate the secondaries. In order that the error resulting from this assumption may be corrected, a factor, $B(X_{ij}, E)$, is included in Equation 5-1. Initially, this correction function was taken to be unity in the dose calculation. The resulting doses compared reasonably well with the detailed calculations of LPPC in identical shield configurations. For example, a number of multilayer shields consisting of aluminum, iron, polyethylene and tissue were analyzed. These

shields totaled 20 gm/cm^2 in thickness. The Dose Code results were low by 1.0 to 2.4 percent. Further studies were conducted for water, aluminum, and iron shields ranging in thickness from zero to 100 gm/cm^2. The comparisons with LPPC data are shown in Figures 5-1, 5-2, and 5-3.

The above comparisons show that the Dose Code results are generally lower than LPPC results by up to 10 percent at 50 gm/cm^2 and up to 20 percent at 100 gm/cm^2. The correction function, B, given in Equation 5-2 permits a better fit.

$$B(X_{ij}, E) = \sum_{k=1}^{M} \exp(.005\, X_{ijk} \cdot A_k/27) \qquad (5\text{-}2)$$

X_{ijk} = k^{th} material thickness in i^{th} solid angle for the j^{th} detector;
A_k = material-dependent parameter (effective atomic weight).

In order to compute the proton flux, $P(X_{ij}, E)$, arriving at the j^{th} detector through the i^{th} solid angle, it is necessary to consider the range relations for protons penetrating a multilayer shield. The range is approximated by Equation 5-3.

$$R(E) = \frac{a}{2b} \cdot \ln(1 + 2bE^r) \qquad (5\text{-}3)$$

where $R(E)$ = proton range at energy E
a, b, r = parameters

Values of a, b, and r are presented in Volume I of this report for a variety of materials.

After penetrating a shield X gm/cm^2 thick, corresponding to an energy loss $(E_o - E_1)$, the range equation becomes:

$$R(E_o) = X + R(E_1) \tag{5-4}$$

or

$$\frac{a}{2b} \ln(1 + 2bE_o^r) = X + \frac{a}{2b} \ln(1 + 2bE_1^r) \tag{5-5}$$

Solving Equation 5-5 for E_o^r:

$$E_o^r = A + BE_1^r \tag{5-6}$$

Where $B = \exp(2bX/a)$

$$A = \frac{B - 1}{2b}$$

Equation 5-6 relates the exit energy to the incident energy for protons penetrating one material.

The above treatment may be readily generalized to multilayer shields. Given two layers, X_1 and X_2, of different materials, the exit energies E_1 and E_2 are related to the incident energy E_o by:

$$E_o^r = A_1 + B_1 E_1^r \tag{5-7}$$

$$E_1^r = A_2 + B_2 E_2^r \tag{5-8}$$

Substituting Equation 5-8 into 4-7,

$$E_o^r = A_1 + B_1 A_2 + B_1 B_2 E_2^r$$

or

$$E_o^r = A' + B' E_2^r \tag{5-9}$$

For M layers

$$E_o^r = A' + B' E_M^r \tag{5-10}$$

Where $B' = B_1 B_2 B_3 \ldots . B_{M'}$

$A' = A_1 + A_2 B_1 + A_3 B_1 B_2 + \ldots . + A_M B_1 B_2 \ldots . B_{M-1'}$ and

$B_k = \exp(2b_k X_k / a_k)$

$A_k = (B_k - 1)/2b_k$

It should be noted that the value of r is assumed to be material independent in the above treatment while a and b are material dependent.

The proton flux penetrating the shield along the i^{th} vector of the j^{th} detector is related to the incident flux by Equation 5-11. This equation presumes conservation of particles. Corrections due to nuclear interactions and secondaries are discussed above.

$$P(X_{ij}, E_M)\, dE_M = P(0, E_o)\, dE_o \tag{5-11}$$

The exit energy, $E_{M'}$ as determined from Equation 5-10, must be non-negative.

The incident flux over an energy interval, E_l to $E_{l+1'}$ is represented by a power law expression:

$$P(0, E_o) = H_l E_o^{-q_l}, \quad E_l \leq E_o \leq E_{l+1} \tag{5-12}$$

One to one hundred intervals may be used over the entire energy range.

The differential of Equation 5-10 is:

$$dE_o = (A' + B'E_M^r)^{\frac{1-r}{r}} dE_M \qquad (5\text{-}13)$$

The flux at the detector is obtained by substituting Equations 5-10, 5-12, and 5-13 into 5-11.

$$P(X_{ij}, E_M)\,dE_M = H_l B'E_M^{r-1}(A' + B'E_M^r)^{\frac{1-q_l-r}{r}} dE_M \qquad (5\text{-}14)$$

with the restrictions

$$E_l^* \leq E_M \leq E_{l+1}^*$$

$$E_l^* = \text{Max}\left[0, \left(\frac{E_l^r - A'}{B'}\right)^{\frac{1}{r}}\right] \qquad (5\text{-}15)$$

$$E_{l+1}^* = \text{Max}\left[0, \left(\frac{E_{l+1}^r - A'}{B}\right)^{\frac{1}{r}}\right]$$

The stopping power of the detector material is given by:

$$S_i(E_M) = \frac{1}{\left(\frac{dR(E)}{dE}\right)_{E_M}}$$

where, from Equation 5-3

$$\frac{dR(E)}{dE} = \frac{a_j r_j E^{r_j - 1}}{(1 + 2b_j E^{r_j})}$$

or

$$S_j(E) = \frac{1 + 2b_j E^{r_j}}{a_j r_j E^{r_j - 1}} \qquad (5\text{-}16)$$

Here, the parameters a, b, and r are subscripted with the detector subscript, j, to indicate that energy is deposited in the detector material. Note that a single value of r must be used for computing slowing through all shield materials but an optimum value may be used to compute energy deposition in the detector material to improve accuracy.

Applying Equations 5-2, 5-14, 5-15, and 5-16 to 5-1, the dose at the j^{th} detector may be written as follows:

$$D_j = K \cdot \sum_{i=1}^{N} \Omega_{ij} \prod_{k=1}^{M} \exp(.005 X_{ijk} \cdot A_k/27) \sum_{l=1}^{L-1} H_l \cdot I_l(E_l^*, E_{l+1}^*) \qquad (5\text{-}17)$$

For non-zero shield thickness,

$$I_l(E_l^*, E_{l+1}^*) = B' \int_{E_l^*}^{E_{l+1}^*} \frac{E_M^{r-1} (A' + B' E_M^{r})^{\frac{1 - q_l - r}{r}} (1 + 2b_j E_M^{r_j})}{a_j r_j E_M^{r_j - 1}} dE_M$$

(5-18)

The following change of variable transforms Equation 5-18 into a form involving incomplete beta functions.

$$t = \frac{B' E_M^{\,r}}{A' + B' E_M^{\,r}}, \quad E_M = \left[\frac{A' t}{B'(1-t)}\right]^{1/r}$$

$$dE_M = \frac{1}{r} \cdot \left(\frac{A'}{B'}\right)^{1/r} \cdot \frac{t^{\frac{1-r}{r}}}{(1-t)^{\frac{1+r}{r}}}\, dt$$

which leads to

$$I_l(E_l^*, E_{l+1}^*) = K_o \left[\beta_{\alpha_2}(u, v) - \beta_{\alpha_1}(u, v) + K_1 \beta_{\alpha_2}(u', v') - K_1 \beta_{\alpha_1}(u', v')\right] \tag{5-19}$$

where $K_o = (A')^{\frac{2 - q_l - rj}{r}}$

$$K_1 = 2bj\left(\frac{A'}{B'}\right)^{\frac{rj}{r}}$$

$$\beta_\alpha(u, v) = \int_o^\alpha t^{u-1} \cdot (1-t)^{v-1}\, dt$$

$$u = \frac{1 - rj - r}{r}$$

$$v = \frac{q_l + rj - 2}{r}$$

$$u' = \frac{1 + r}{r}$$

$$v' = \frac{q_l - 2}{r}$$

$$\alpha_2 = \text{Max}\left[0,\ 1 - A'E_{l+1}^{-r}\right]$$

$$\alpha_1 = \text{Max}\left[0,\ 1 - A'E_l^{-r}\right]$$

E_l and E_{l+1} are specified by Equation 5-12.

The incomplete beta function is evaluated by:

$$\beta_\alpha(u, v) = \frac{\alpha^u}{u} \cdot \Gamma(u, 1 - v, u + 1, \alpha) \qquad (5\text{-}20)$$

for $0 < \alpha < 1$ with v negative and for $0 < \alpha \leq 1/2$ with v positive. If v is positive and $1/2 < \alpha < 1$,

$$\beta_\alpha(u, v) = \frac{\Gamma(u)\cdot\Gamma(v)}{\Gamma(u + v)} - \beta_{1-\alpha}(v, u). \qquad (5\text{-}21)$$

Here, $\Gamma(a, b, c, x)$ is the hypergeometric series.

$$\Gamma(a, b, c, x) = 1 + \frac{a\,b}{c} \cdot x + \frac{a(a + 1)\,b(b + 1)}{c(c + 1)} \frac{x^2}{21} + \ldots \qquad (5\text{-}22)$$

The hypergeometric series is truncated at a point where the last term does not contribute to the eighth significant figure.

For zero thickness shields or for high energy protons penetrating thin shields, Equation 5-18 takes the following form.

$$I_l(E_l^*, E_{l+1}^*) = \frac{B'}{a_j r_j} \int_{E_l^*}^{E_{l+1}^*} E^{l - q_l - r_j}\cdot(1 + 2b_j E^{r_j})\, dE \qquad (5\text{-}23)$$

The code evaluates analytical solutions of this equation for all values of the exponents.

The dose at the j^{th} detector is obtained by means of Equation 5-17, using 5-18 or 5-23 as appropriate. The code has been tested for positive, zero, and negative power law spectra, and for shield thicknesses ranging from 0.004 gm/cm^2 to 100 gm/cm^2 plus zero shield thickness.

5.2 SPECIAL FEATURES

The Dose Code treats an unrestricted number of detectors. The only limitation is imposed by the number of detector positions prepared by the Geometry Code which also treats an unrestricted number of detectors. The Dose Code may be instructed to ignore some of the detectors on the geometry tape and to rewind the geometry tape in order to process the detectors again, possibly with a different input spectrum.

The detector dose calculations are performed vector by vector; therefore, the dose may be tallied into solid angle regions specified by the user. The solid angle regions may be discrete, nested, or partially overlapped. This feature permits the user to check the relative importance of shield sections and determine the effect of streaming.

The Dose Code is designed to facilitate parametric studies. Material densities may

be changed, even zeroed, with the "FF" values. This procedure effectively changes material penetration thicknesses. The range parameters associated with material numbers may be altered. These two features permit changes in shield materials and thicknesses without preparing a new geometry tape. In this context, the term "shield" refers to any set of volume elements in the configuration. These features, in conjunction with the capability of changing the input spectrum and rewinding the geometry tape, permit extensive parametric investigations with one access to the computer.

It should be noted that alpha range parameters may be substituted for proton range parameters. Hence, the Dose Code may be used to estimate dose due to alphas inside relatively thin shields. Secondary processes must be investigated before reliable estimates of dose due to alphas can be made for thick shields.

5.3 DOSE PROGRAM DATA INPUT PREPARATION

In the following, the column headed "FORMAT" gives the DIP format control under which this data is to be read, the column headed "NAME" gives the name of the data array, the column headed "DIMENSION" indicates the number of words available in fast storage for the named array, and the column headed "DEFINITION" is an attempt to describe the named data array.

The NAME card for the following data set must be:

N16, PHI, E, MAT, SA, SB, R1, HEAD, NPHI, NM, N2, ND, BIN, FDC, UNITS, FF, AT

(See the description of the DIP program - Appendix A.1.)

FORMAT	NAME	DIMENSION	DEFINITION
3	PHI	(100)	Free field proton flux (P/cm^2-MeV-ster.)
3	E	(100)	Energies (MeV) associated with the tabulated proton flux (PHI)

NOTE: PHI and E must be tabulated in order of increasing energy.

4	MAT	(1000)	Material numbers (an identification number); these numbers MUST match the material numbers (MVX) in the Geometry Program. The order of the MAT's is immaterial. This list should contain a material number only once for each material regardless of the number of times the material appears in the geometric configuration. The list should also include the material number of each detector; however, if more than one detector is of the same material, the number need only be entered once. Detector material numbers MUST NOT be first in the list.
3	SA	(1000)	Parameters associated with the range equation: $R(E) = \frac{a}{2b} \ln (1 + 2b E^r)$, SA = a,
3	SB	(1000)	SB = b, and R1 = R.
3	R1	(1000)	The number of each of the parameters must equal the number of MAT's and must be ordered to correspond to the materials in the MAT list. All the R1's must be equal, except those that refer to detector materials.

FORMAT	NAME	DIMENSION	DEFINITION
(SA, SB, R1 - Continued)			(See Volume I)
5	HEAD	(20)	Any set of alphanumeric and special character information to identify the particular case at hand.
4	NPHI	(1)	The number of entries in the PHI-table.
4	NM	(1)	The number if entries in the MAT-table.
4	N2	(1)	The logical number of the tape unit upon which the geometry tape is to be mounted.
4	ND	(1)	The number of detectors associated with this particular geometry tape. (If ND is zero, the program ends immediately with a memory dump; if ND is negative, the program ends with no dump. One of these methods should be used to cease the calculations.)
5	BIN	(1)	Hollerith information indicating the storage location of the geometry tape.
3	FDC	(1)	Flux-to-dose conversion factor.
5	UNITS	(3)	Hollerith information consistent with FDC. (Usually RAD/HR or RAD).

FORMAT	NAME	DIMENSION	DEFINITION
3	FF	(1000)	A factor, associated with each material, for adjusting the density (or thickness-gm/cm^2) of the material. The FF's must be in the same "order" as the MAT's. A value of unity preserves the penetration thicknesses computed by the Geometry Program.
3	AT	(1000)	A factor for adjusting buildup; this value should approximate the atomic mass number of the volume element with which it is associated. AT should equal zero if buildup is not needed. The AT's must be in the same "order" as the MAT's. (See Equation 5-2)

Control must be returned to the program after the above data is read.

The following data are input in a do-loop over the number of detectors, ND.
The NAME card associated with this data set is:

N4, NAR, POLA, AZIM, NSKIP

FORMAT	NAME	DIMENSION	DEFINITION
4	NAR	(1)	Number of angular regions. This indicates the number of partial solid angle regions into which the dose is to be tallied for the detector of current interest. If the sum of the mutually exclusive partial solid angular regions is less than 4π, the dose in the remaining

FORMAT	NAME	DIMENSION	DEFINITION
4	NAR (Continued)	(1)	solid angle is also tallied. The total dose at the detector is calculated whether NAR is zero or not. NAR must not be greater than 150.
3	POLA	(300)	The polar angle limits of the angular region - two polar angles per region.
3	AZIM	(300)	The aximuthal angle limits of the angular region - two azimuthal angles per region.

NOTE: All angles are in degrees and are positive; the lower limit must be the first of the pair. The polar angles must lie between 0° (positive z-axis of configuration) and 180° (negative z-axis of configuration) inclusive. The polar angle lower limit must be less than the upper limit. The azimuthal angles are measured counter clock-wise from the configuration positive x-axis. The azimuthal angles must lie between 0° and 360° inclusive. The azimuthal angle lower limit need not be less than the upper limit. For example, the data card to define two angular regions - (1), the first octant, and (2), a special region defined by the polar angles 20° to 160°, and the azimuthal angles - 45° to 45°, will have the following format:

4NAR, 2, 3POLA, 0, 90, 20, 160, AZIM, 0, 90, 315, 45

4	NSKIP	(1)	If this value is greater than zero, the current detector is processed; if this value is less than or equal to zero the current detector is skipped.

See sample input data listing in Appendix A.2.

5.4 DOSE CODE OUTPUT

A sample output is shown in Appendix A.2. The first line is a general heading for the case. A spectrum table follows giving energy, flux, and the power law parameters H and q. Next, the detector heading card, detector coordinates, and detector material number (all obtained from the geometry tape) are printed. The next line, indicated by five asterisks on the right, shows detector number and total dose. If solid angle bins are specified, their tallies follow. The polar and azimuthal angle limits are given in degrees. PARTIAL DOSE is the dose entering within a particular solid angle. The WT. FRACTION column measures the relative contribution of a particular solid angle bin. It is the ratio of partial dose to total dose, divided by the ratio of solid angle to four pi steradians. The solid angle is also given. The final row after the last solid angle bin gives similar information for any vectors not contained within one or more angular bins.

6.0 MISSION FLUX PROGRAM

The Mission Flux Program calculates proton and electron fluxes integrated over trajectories through the trapped radiation belts of Earth. Arbitrary trajectories may be specified point by point; alternatively, orbital parameters may be specified and the program will calculate up to 150 positions equally spaced in time for a single orbit. The geographic coordinates are converted to B-L coordinates and logarithmic interpolation is performed in flux tabulations. The total integrated fluxes over the trajectory are calculated using a parabolic numberical integration routine.

The radiation data are taken from the Vette model environments[7]. The omnidirectional electron data is for the region of space below L = 3. The model spectrum is independent of B and is exponential above 2 MeV. It is divided into 7 energy groups ranging from 0.5 to 7 MeV, plus one group above 7 MeV. The electron data is for the January - September 1963 time period. The proton model spectrum is dependent on both B and L. The program calculates omnidirectional proton flux above energy E for 12 values of energy ranging from 4 to 1000 MeV. The electron and proton spectra may be converted to number flux, differential in energy, with the aid of the Lockheed Source Spectrum Code[3].

6.1 MISSION TRAJECTORY

The vehicle trajectory may be specified in a table of geographic coordinates (R, Φ, λ) versus time (t). Here, R is the radius vector; Φ is the north latitude ($+90^{\circ}$ at North Pole, -90° at South Pole); and λ is the east longitude.

The program converts these coordinates to a right-handed Cartesian system with the y- axis directed through zero longitude and the z-axis directed through the North Pole. The conversion is:

$$
\begin{aligned}
x(t) &= R(t) \cos(\Phi(t)) \sin(\lambda(t)), \\
y(t) &= R(t) \cos(\Phi(t)) \cos(\lambda(t)), \\
z(t) &= R(t) \sin(\Phi(t)).
\end{aligned}
\tag{6-1}
$$

Orbital trajectories may be specified by providing 7 orbital parameters. These parameters are:

P = altitude at perigee

Φ_P = north latitude at perigee

λ_P = east longitude at perigee

α = inclination of orbit with respect to equatorial plane - always positive

e = eccentricity of orbit

$$
\text{RSENSE} = \begin{cases} +1. & \text{west to east orbit} \\ -1. & \text{east to west orbit} \end{cases}
$$

$$
\text{OSENSE} = \begin{cases} +1. & \text{vehicle climbs north from perigee} \\ -1. & \text{vehicle descends south from perigee} \end{cases}
$$

The initial point is taken to be at perigee. A stationary right-handed coordinate system (x_c, y_c, z_c) is defined with the origin at the center of the Earth, the z-axis through the North Pole, and the x-axis specified by the projection of the northernmost orbital point in the equatorial plane. In this coordinate system, the initial position at time $t = 0$ is:

$$
\begin{aligned}
x_c(0) &= P \cdot \cos\theta \cdot \cos\alpha, \\
y_c(0) &= \text{RSENSE} \cdot P \cdot \sin\theta, \\
z_c(0) &= P \cdot \cos\theta \cdot \sin\alpha,
\end{aligned}
\tag{6-2}
$$

where θ is the angle between the radius vector through the northernmost orbital point and the radius vector through perigee. The angle θ is defined by:

$$\cos\theta = \frac{\sin\Phi_P}{\sin\alpha} \; ; \; \sin\theta = -\,\text{OSENSE} \cdot (1 - \cos^2\theta)^{1/2} . \qquad (6\text{-}3)$$

The initial velocity vector in the (x_c, y_c, z_c) system is:

$$\begin{aligned} \dot{x}_c(0) &= -\,v \cdot \sin\theta \cdot \cos\alpha , \\ \dot{y}_c(0) &= \text{RSENSE} \cdot v \cdot \cos\theta , \\ \dot{z}_c(0) &= -\,v \cdot \sin\theta \cdot \sin\alpha , \end{aligned} \qquad (6\text{-}4)$$

where the initial velocity, v, is:

$$v = \frac{g \cdot (1 + e)}{P} \qquad (6\text{-}5)$$

The quantity g is the universal gravitational constant multiplied by the mass of the Earth; $3.985 \times 10^{14} \, m^3/sec^2$.

The equations of motion of a small orbiting body, neglecting certain perterbations, may be expressed as:

$$\begin{aligned} \ddot{x}_c &= g\, x_c (x_c^2 + y_c^2 + z_c^2)^{-3/2} \\ \ddot{y}_c &= g\, y_c (x_c^2 + y_c^2 + z_c^2)^{-3/2} \\ \ddot{z}_c &= g\, z_c (x_c^2 + y_c^2 + z_c^2)^{-3/2} \end{aligned} \qquad (6\text{-}6)$$

Subject to the initial conditions, Equations 6-2 and 6-4, numerical solutions of Equations 6-6 are obtained by the application of the Runge - Kutta - Gill integration formulae. The fourth iteration is accepted as a solution, and up to 150 equal time intervals are treated.

The position coordinates in the stationary (x_c, y_c, z_c) system are transformed to a

physical analogue of the equatorial radius in a pure dipole field. It is computed from the relations;

$$\ln\left(\frac{L^3 B}{M} - 1\right) = \sum_{n=0}^{6} a_n x^n \qquad (6\text{-}11)$$

where

$x = \ln\left(\frac{I^3 B}{M}\right)$

M = dipole moment of the Earth

a_n = polynomial coefficients determined by McIlwain.

The magnetic field, B, and its components are derived from the gradient of a geomagnetic potential function, V, which is represented by a 48 term, spherical harmonic expansion. This function, as presented by Vestine[6], is given by:

$$V = a \sum_{n=1}^{6} \left(\frac{a}{r}\right)^{n+1} T_n \qquad (6\text{-}12)$$

where

$$T_n = \sum_{m=0}^{n} \left(g_n^m \cos m\lambda + h_n^m \sin m\lambda\right) P_n^m(\theta)$$

and

a = radius of Earth (6371.2217 km)

r = radius vector from geocenter

λ = east longitude

θ = colatitude

$P_n^m(\theta)$ = partially normalized associated Legendre polynomials

g_n^m, h_n^m = Gauss coefficients*

The magnitude of B is obtained from

$$B_x = \frac{\partial V}{\partial x}, \quad B_y = \frac{\partial V}{\partial y}, \quad B_z = \frac{\partial V}{\partial z}$$

$$B = (B_x^2 + B_y^2 + B_z^2)^{1/2}$$

The value of the longitudinal invariant I, defined in Equation 6-10, is evaluated by integrating along a line of force. Errors due to truncation and departures from the original line of force are kept small by requiring the step size to meet two constraints. First, the relative change in magnetic field must be less than an input quantity EPS, generally .05. Second, the step size, expressed in Earth radii, must be less than 2 x EPS.

6.3 GLOSSARY OF INPUT DATA TERMS

W(I, J) $g_{I-1,\ J-1}$ terms for spherical harmonic expansion of geomagnetic field

V(I, J) $h_{I-1,\ J-1}$ terms for spherical harmonic expansion of geomagnetic field

BLLS(I, J) I^{th} value of magnetic field B for J^{th} L value in table of proton spectral constants above 50 MeV

PLLS(I, J) proton exponential energy spectrum parameter, E_o, corresponding to BLLS(I, J)

* The sample case uses Finch - Leaton[2] coefficients for Epoch 1955.

PLL1(J)	J^{th} value of L for table of proton flux above 4 MeV versus B and L
BFLSP1(I, J)	I^{th} value of B for J^{th} value of L in table of proton flux above 4 MeV versus B and L
PFLS1(I, J)	proton flux above 4 MeV corresponding to PLL1(J) and BFLSP1 (I, J)
PLL2(J)	J^{th} value of L for table of proton flux above 15 MeV versus B and L
BFLSP2(I, J)	I^{th} value of B for J^{th} value of L in table of proton flux above 15 MeV versus B and L
PFLS2(I, J)	proton flux above 15 MeV corresponding to PLL2(J) and BFLSP2 (I, J)
PLL3(J)	J^{th} value of L for table of proton flux above 34 MeV versus B and L
BFLSP3(I, J)	I^{th} value of B for J^{th} value of L in table of proton flux above 34 MeV versus B and L
PFLS3(I, J)	proton flux above 34 MeV corresponding to PLL3(J) and BFLSP3 (I, J)
PLL4(J)	J^{th} value of L for table of proton flux above 50 MeV versus B and L
BFLSP4(I, J)	I^{th} value of B for J^{th} value of L in table of proton flux above 50 MeV versus B and L
PFLS4(I, J)	proton flux above 50 MeV corresponding to PLL4(J) and BFLSP4 (I, J)
ELLS(I, J)	the fraction of electrons in the I^{th} energy interval for the J^{th} L interval
ELL(J)	J^{th} value of L for table of electron flux above 0.5 MeV versus B and L
BFLS(I, J)	I^{th} value of B for J^{th} value of L in table of electron flux versus B and L

EFLS(I, J)	electron flux above 0.5 MeV corresponding to ELL(J) and BFLS (I, J)
JDATA	option parameter (1) read geographic coordinates of points on trajectory and compute fluxes (2) compute geographic coordinates of points on orbital trajectory and compute fluxes (3) exit (4) dump core, then exit (5) compute geographic coordinates of points on orbital trajectory
KTRAP	option parameter (0) stop computation if L calculation exceeds 1000 iterations (1) force L calculation
NT	number of points on trajectory; less than 151
EPS	step size criterion in calculation of L; normally .05
T(I)	time for I^{th} trajectory point (JDATA = 1)
RG(I)	radial distance of I^{th} trajectory point in kilometers (JDATA = 1)
PHIG(I)	north latitude of I^{th} trajectory point (JDATA = 1)
FLG(I)	east longitude of I^{th} trajectory point (JDATA = 1)
E	eccentricity of orbit (JDATA = 2 or 5)
ALPHAI	inclination of orbit (JDATA = 2 or 5)
P	altitude of orbit above surface of Earth in kilometers (JDATA = 2 or 5)
OT	period of orbit in minutes (JDATA = 2 or 5)
FLNO	east longitude of perigee (JDATA = 2 or 5)
FLAT	north latitude of perigee (JDATA = 2 or 5)
RSENSE	rotation parameter + 1. west to east orbit -1. east to west orbit

RSENSE (continued)

(JDATA = 2 or 5)

OSENSE orbital direction parameter

+ 1. trajectory proceeds north from perigee

- 1. trajectory proceeds south from perigee

(JDATA = 2 or 5)

6.4 INPUT DATA PREPARATION

NOTE: The following cards follow the *(asterisk) DATA card.

CARD TYPE 1 Fourteen cards contain the Gauss coefficients; $g_0^0, g_1^0, \ldots g_6^0, g_0^1, g_1^1, \ldots \ldots, g_6^6, h_0^0, h_1^0, \ldots h_6^0, h_0^1, h_1^1 \ldots, h_6^6$. Fifty of these coefficients are not used.
FORMAT (7E10.)

CARD TYPE 2 This card group contains about 1500 cards describing proton fluxes in the inner belt. Five subgroups contain the exponential energy parameter above 50 MeV and the proton maps AP4, AP2, AP1, and AP3. The data deck is identical to the deck furnished by Vette[7] except that blanks are filled and a typographical error in one L value has been corrected.

CARD TYPE 3 Thirteen cards contain a table of electron spectrum weighting factors versus L. FORMAT (8E9.)

CARD TYPE 4 This card deck contains the electron flux map, AE1, of Vette[7].

The following data are designated case cards. Each case is specified by one Card Type 5 and multiple Cards Type 6, or one Card Type 5 and one Card Type 7.

Multiple case runs are permissible.

CARD TYPE 5 This card contains five input parameters as follows:

JDATA option parameter

(1) read trajectory points on Cards Type 6 and compute fluxes

(2) read orbit parameters on Card Type 7 and compute fluxes

(3) EXIT

(4) DUMP, then EXIT

(5) read orbit parameters on Card Type 7, do not compute fluxes

KTRAP invariant parameter

(0) stop the calculation if I requires 1000 steps

(1) ignore KTRAP

NT the number of trajectory points to be processed must not exceed 150

EPS governs accuracy of I and L calculation, usually 0.05

IPRT intermediate print option

(0) no detailed print

(1) detailed print

FORMAT (2I1, I3, E10., I5)

CARD TYPE 6 This card contains trajectory information including time in seconds, radial distance in kilometers, north latitude, and east longitude in degrees. FORMAT (4E10.)

CARD TYPE 7 This card contains orbital parameters.

E eccentricity of orbit

ALPHAI inclination of orbital plane to equatorial plane in

	degrees (positive)
P	altitude of perigee above surface of Earth in kilometers
OT	orbit time in minutes, will be calculated if not input
FLNO	east longitude of perigee in degrees
FLAT	north latitude of perigee in degrees
RSENSE	+ 1., west to east orbit
	- 1., east to west orbit
OSENSE	+ 1. orbit north from perigee
	- 1. orbit south from perigee

6.5 MISSION FLUX PROGRAM OUTPUT

The Mission Flux Program prints a table of trajectory position versus time at NT points. Position is given in a right-handed Cartesian coordinate system rotating with the Earth. The z-axis goes through the North Pole and the y-axis is in the equatorial plane and through the Greenwich meridian. Units are in terms of Earth radii, 6371.2217 kilometers.

If JDATA is set to 1 or 2, a flux calculation is performed and a table labeled "Trajectory and Flux in B-L Space" is printed. This table contains time in seconds, B in Gauss, L, omnidirectional proton flux above 4 MeV, omnidirectional electron flux above 0.5 MeV, and KTR, the number of mesh points along the magnetic line of of force required to evaluate the invariant, I. Flux units are particles per square centimeter - second.

The calculation of B, L, and particle fluxes is omitted if the trajectory point is within approximately 25 degrees from either pole. The calculation of L and particle fluxes is omitted if B is greater than 0.305 Gauss. The former criterion neglects that region of space where fluxes are small and computational effort is large. The latter criterion neglects that region of space where proton fluxes are trivial and

electron fluxes are less than 2×10^3. Here, the interpolation scheme sometimes produces erroneous electron fluxes greater than 10^6.

Finally, two tables of proton flux above energy E and electron flux above energy E versus energy in MeV are printed. These fluxes are integrated over the trajectory. The units are omnidirectional particles above energy E per square centimeter.

APPENDIX A.1

APPENDIX A.1

IDENTIFICATION	GLDIP1, Format Free Input Routine
ENTRY POINTS	GLDIP1, DIP, (DIP)
DECIMAL LOCATIONS	655

USAGE AND INFORMATION

The DIP Program is a FAP language subroutine designed to facilitate the preparation of data for acquisition by a calling program. No format statements are required in the calling program when data is input through the DIP subroutine.

The calling sequence required for the use of DIP is:

CALL DIP (IN, J, A, B, C, ...)

IN is the BCD input tape assignment obtained by:

CALL TAPE (2, IN, 10);

J is the number of names in the input list;

A, B, C, . . . are the names in the input list and must be the same as the names for these quantities in the program. The maximum number of names in any one calling sequence is 50.

The format of a data card is controlled by a character in column 1 of the card. If

column 1 contains a

3, the data is floating point.

4, the data is fixed point.

5, the data is hollerith information.

8, control is transferred immediately to EXIT.

9, the card and all information therein is ignored and the next card is read; i.e., this is a comments card.

N, this indicates a "name" card and contains a list of names which correspond to the names in the calling sequence list.

@, input processing ceases with the data on this card, and the data is fixed point. Control is returned to the calling program.

=, input processing ceases with the data on this card, and the data is floating point. Control is returned to the calling program.

*, input processing ceases with the data on this card, and the data is in the same format as the card immediately preceding it. Control is returned to the calling program.

(blank), the data is in the same format as the preceding card.

The name of the array to which the data pertains must precede the data: further, the name must be separated from the data by a comma or a blank, and the data "words" must be separated from each other by commas or blanks. For example,

3A, 1, 2, 3.5, 7, 20, X, .6, -.05, 100, PRT, 15

The 3 in column 1 indicates floating point data; A is the name of a data array; 1 is stored in A(1); 2 is stored in A(2); etc.; X is the name of another array and so is

PRT. Columns 2 through 72 inclusive may be used for array names, data, and hollerith information. Array names and data names that are not completed on or before column 72 can be continued on the next card, starting in column 2. Data words may be separated by 1 or more blanks and/or commas. Since the blank or comma after each data word is a signal to store the data word in the proper location, if a data word ends in column 72, the following card must have a blank or asterisk in column 1 and a blank or comma in column 2.

In addition to the control characters in column 1, there are other control characters available which may be used in any column 2 through 72. The interpretation of this character is:

= m, the next m storage locations in the name array remain unchanged. For example:

Y, 10, 1.5, = 6, 12, 7,

1.5 is stored in Y(2), 12 is stored in Y(9), and locations Y(3) through Y(8) are unchanged. If an array name is not in a data set, the entire array remains unchanged throughout the processing of that data set by DIP. At least one data word in addition to the "=m" must be present with the "=m" or an error indication will result.

z/n, the number z is to be stored in the next n storage locations. For example:

Y, 10, 1.5, 13/10, 12, 7,

1.5 is stored in Y(2), 13 is stored in Y(3) through Y(12) inclusive, and 12 is stored in Y(13). z/1 and z/0 will cause an error indication.

$, this character in a column results in the column immediately following to be treated as though it were column 1. For example:

3A, 1, 2, 3, $4KQ, 1, 2, 3, $9

The 3 in column 1 causes the data for the A-array to be processed as floating point; the 4 after the $causes the KQ-array to be processed as fixed point data; the 9 after the second $ causes the rest of the card to be ignored. A $ in column 1 or 72 will result in an error indication.

Integral powers of ten associated with a number are indicated only by a '+' or '-' before the exponent. That is, 6.35-5 is 6.35×10^{-5}, and -4.32+ 5 is -4.32×10^{5}. A decimal point in the exponent will cause an error indication.

The "name" card, a card with an N in column 1, must precede any array names in the data cards. The format for the name card is:

N, J, A, B, C, . . .

N is in column 1;

J is the number of names in the list;

A, B, C, are the array names and must be in the same order as the list in the calling sequence that reads this data. Additional name cards are required only when the calling sequence changes or the array names change.

Array names for data may be as large as six characters in length and must start with an alphabetic character. With the exception of the first character, which must be alphabetic, the array name may have any alpha-numeric character.

If, while processing data, a data error is detected, the DIP subroutine indicates an error has been found and prints the card image. Following this, the remaining data are searched for further errors and the card images of any additional errors are printed; the DIP subroutine then transfers control to EXIT, or to DUMP if *DUMP or *DUMPM is present.

The format for the 5-card (i.e., the card with a 5 in column 1 for reading hollerith data) is:

5HEAD, J, HOLLERITH INFORMATION

HEAD is the name of the hollerith list, and

J is the number of machine words required to store the information, in this case four - six characters per word, including blanks.

When the "word" count, J, has been satisfied, the next data card is read; hence, format changes cannot be made in cards with a 5 in column 1. Hollerith data may be carried through two or more cards providing the "word" count is consistent with the amount of information to be stored.

If the input data are not subsequently altered by the program, a parametric study may be conducted by using the =m and z/n feature of DIP to change only the parameters affected. Hence a second or third or further case will not have to re-read all the input data; it will have to read only that which changes. For subsequent cases the N card may be deleted; unless a second N card has been read. This is true since DIP retains the most recent N card, and any data read should conform to the array names on that N card.

ERROR INDICATION

On finding one error, the remaining data are searched and the card images are listed off-line for any cards in error or possibly in error.

APPENDIX A.2

PROGRAM
INPUT AND OUTPUT
LISTINGS

GEOMETRY PROGRAM

INPUT DATA LISTING

```
*      DATA
N18 NX NXQ MVX RHX XXI YYI ZZI XX YX ZX KQ RA PR ARY TX TY TZ NTRNS
9      STANDING MAN MODEL
       TOP REGION OF HEAD
4NTRNS 1 $3ARY 1 0/3 1 0/3 1 TX 0 TY 36 TZ -42 $9
4MVX 201 NX 1 NXQ 1 KQ 1 $3RHX 2.54 XXI 0 YYI 0 ZZI 70 RA 2.8 PR 2.8 XX     SM 01
*12 0/4 4.8 YX 0/2 12 0/3 ZX 69.2/3 70 71 69.2 $9                           SM 02
9      MAIN REGION OF HEAD
4NX 2 NXQ 3 KQ 3 1 1 $3ZZI 68 RA 2.5 .6/2 PR .25 .6/2 XX =3 -2.4/2 4.8 .    SM 03
 7 1.2 4.8 4.3/2 4 4.3/2 4 YX =3 -12 12/2 0/3 -1.2/2 -1.8 ZX =3 65.2/2 6    SM 04
*2.8 68 66 69.2 68 68.6 68/2 68.6 68 $9                                     SM 05
9      NECK REGION
4NX 2 NXQ 2 KQ 3 2 $3ZZI 62 RA 2 5.4 PR .125 XX -2.4/2 4.8 -12/2 12 0 .2    SM 06
  3.2 .6/2 6 YX -12 12/2 -12 12/2 0/3 -12 12/2 ZX 65.2/2 62.8 55.6/3 61.    SM 07
*4  63/2 55.6/3 $9                                                          SM 08
9      SHOULDERS
4NX 1 KQ 2 3 $3ZZI 58 RA 5.4 8.8 PR 0 .04838 XX -12/2 12 .6/2 6 .6 .4 6     SM 09
*YX -12 12/2 -12 12/2 0/3 ZX 55.6/7 47.4 55.6 $9                            SM 10
9      LOWER CHEST
4NX 2 NXQ 1 KQ 3 $3ZZI 48 RA 6.8 PR .03226 XX =3 -12/2 12 .6 .4 6 ZX =3     SM 11
*43.2/3 55.6 47.4 55.6 $9                                                   SM 12
9      HIP REGION
=ZZI 40 RA 7 PR .0625 XX =6 -.6 0 -6 ZX 43.2/3 33.6/4 43.2 33.6 $9          SM 13
9      UPPER RIGHT LEG
3YYI -4 ZZI 27 RA 3.6 PR .17963 XX =6 -.6 0 -6 YX =6 -3.6 -4.7 -3.6 ZX 3    SM 14
*3.6/3 18.7/3 33.6 18.7 33.6 $9                                             SM 15
9      UPPER LEFT LEG
=YYI 4 YX =6 3.5 4.7 3.5 $9                                                 SM 16
9      LOWER RIGHT LEG
3YYI -5.6 ZZI 12 RA 2.1 PR .06206 XX =6 0/2 2.7 YX =6 -5 -6.2 -4.7 ZX 18    SM 17
*.7/3 4.2/3 16 7.2 18.7 $9                                                  SM 18
9      LOWER LEFT LEG
=YYI 5.6 YX =6 5 6.2 4.7 $9                                                 SM 19
9      RIGHT FOOT
4NX 7 NXQ 0 $3XXI 4 YYI -7 ZZI 2 RA 0 PR 0 XX 9.6/3 -1.8/3 -12/2 12 -12/    SM 20
 2 12 1.8/2 9.6 12 -12/2 12 -12/2 YX =6 -12 12/2 -12 12/2 -12 12/2 -4.6/    SM 21
 2 -5.2 -8.6/2 -9.2 ZX 5/2 -1 5/2 -1 4.2/3 0/3 4.2/2 1.2 4.2/2 0 4.2/2 0    SM 22
* $9
9      LEFT FOOT
=YYI 7 YX =15 4.6/2 5.2 8.6/2 9.2 $9                                        SM 23
9      UPPER RIGHT ARM
4NX 0 NXQ 2 KQ 3 2 $3XXI 0 YYI -10 ZZI 56 RA 1.9 5.4 PR .07143 XX 0/2 2.    SM 24
*3 .6/2 6 YX -9 -10/2 -12 12/2 ZX 54 47/2 55.6/3 $9                         SM 25
9    UPPER LEFT ARM
=YYI 10 YX 9 10/2 =2 12 $9                                                  SM 26
9      MIDDLE RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 48 RA 1.9 XX -12/2 12 -12/2 12 0/2 2.3 YX    SM 27
* -12 12/2 -12 12/2 -9 -10/2 ZX 55.6/3 43.2/3 54 47/2 $9                    SM 28
9      MIDDLE LEFT ARM
=YYI 10 YX =6 9 10/2 $9                                                     SM 29
9      LOWER RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 41 RA 1.4869 PR .0625 XX =3 -12/2 12 0/2     SMA30
*1.8 YX =3 -12 12/2 -10.6 -10.9 -10.6 ZX 43.2/3 33.6/3 40 35.2 40 $9        SMB30
9      LOWER LEFT ARM
=YYI 10 YX =6 10.6 10.9 10.6 $9                                             SM 31
9      RIGHT HAND
4NX 1 KQ 1 $3YYI -10 ZZI 30.5 RA 2.2 PR 3.8 XX =3 0/2 1.4 YX =3 -11/3 ZX    SM 32
* 33.6/3 31 29 31.4 $9                                                      SM 33
9      LEFT HAND
```

```
=YOI 10 YX =3 11/3 $9                                                    SM 34
9    HEMISPHERICAL CAP
4NTRNS 1 $3ARY 1 0/3 1 0/3 1 TX 0 TY 36 TZ 0 $9  MAN MODEL TRANSFORMATIO  N
4MVX 1 NX 1 NXQ 2 KQ 1 1 $3RHX 6.85546 XXI 0 YYI 0 ZZI 66.5 RA 24 25 PR   TC  01
*24 25 XX 0 1 0/7 YX 0 0 1 0 0 24 0 0 25 ZX 42/3 0 1 42 0 1 42 $9         TC  02
9    CYLINDER VACUUM
4MVX 22 NX 2 NXQ 1 KQ 2 $3RHX 0 ZZI 0 XX =4 1 0/4 YX =5 1 0 0 24 ZX =3 -
*42/3 0 1 0 $9
9    CYLINDER ALUMINIUM BLOCK
4MVX 2 $=RHX 6.85546 YX =8 25 RA 25 $9
9    CONICAL VACUUM
3YX =8 24 $9
4MVX 3 NXQ 1 KQ 3 $=RHX 0 PR 1 YYI 0 ZZI -50 ZX -66/3 =3 0 -1 -42 RA 24
9    CONICAL ALUMINUM BLOCK
4MVX 4 $=RHX 6.85546 RA 25 YX =8 25 ZX -67.4142/3 $9                     TC  06
9      STANDING MAN MODEL
4NTRNS 1 $3ARY -1 0/3 1 0/3 -1 TX 0 TY -36 TZ 42 $9
9      TOP REGION OF HEAD
4MVX 201 NX 1 NXQ 1 KQ 1 $3RHX 2.54 XXI 0 YYI 0 ZZI 70 RA 2.8 PR 2.8 XX   SM 01
*12 0/4 4.8 YX 0/2 12 0/3 ZX 69.2/3 70 71 69.2 $9                        SM 02
9      MAIN REGION OF HEAD
4NX 2 NXQ 3 KQ 3 1 1 $3ZZI 68 RA 2.5 .6/2 PR .25 .6/2 XX =3 -2.4/2 4.8 . SM 03
 7 1.2 4.8 4.3/2 4 4.3/2 4 YX =3 -12 12/2 0/3 -1.2/2 -1.8 ZX =3 65.2/2 6 SM 04
*2.8 68 66 69.2 68 68.6 68/2 68.6 68 $9                                  SM 05
9      NECK REGION
4NX 2 NXQ 2 KQ 3 2 $3ZZI 62 RA 2 5.4 PR .125 XX -2.4/2 4.8 -12/2 12 0 .2 SM 06
  3.2 .6/2 6 YX -12 12/2 -12 12/2 0/3 -12 12/2 ZX 65.2/2 62.8 55.6/3 61.  SM 07
*4  63/2 55.6/3 $9                                                       SM 08
9      SHOULDERS
4NX 1 KQ 2 3 $3ZZI 58 RA 5.4 8.8 PR 0 .04838 XX -12/2 12 .6/2 6 .6 .4 6  SM 09
*YX -12 12/2 -12 12/2 0/3 ZX 55.6/7 47.4 55.6 $9                         SM 10
9      LOWER CHEST
4NX 2 NXQ 1 KQ 3 $3ZZI 48 RA 6.8 PR .03226 XX =3 -12/2 12 .6 .4 6 ZX =3  SM 11
*43.2/3 55.6 47.4 55.6 $9                                                SM 12
9      HIP REGION
=ZZI 40 RA 7 PR .0625 XX =6 -.6 0 -6 ZX 43.2/3 33.6/4 43.2 33.6 $9       SM 13
9      UPPER RIGHT LEG
3YYI -4 ZZI 27 RA 3.6 PR .17963 XX =6 -.6 0 -6 YX =6 -3.6 -4.7 -3.6 ZX 3 SM 14
*3.6/3 18.7/2 33.6 18.7 33.6 $9                                          SM 15
9      UPPER LEFT LEG
=YYI 4 YX =6 3.5 4.7 3.5 $9                                              SM 16
9      LOWER RIGHT LEG
3YYI -5.6 ZZI 12 RA 2.1 PR .06206 XX =6 0/2 2.7 YX =6 -5 -6.2 -4.7 ZX 18 SM 17
*.7/3 4.2/3 16 7.2 18.7 $9                                               SM 18
9      LOWER LEFT LEG
=YYI 5.6 YX =6 5 6.2 4.7 $9                                              SM 19
9      RIGHT FOOT
4NX 7 NXQ 0 $3XXI 4 YYI -7 ZZI 2 RA 0 PR 0 XX 9.6/3 -1.8/3 -12/2 12 -12/ SM 20
 2 12 1.8/2 9.6 12 -12/2 12 -12/2 YX =6 -12 12/2 -12 12/2 -12 12/2 -4.6/ SM 21
 2 -5.2 -8.6/2 -9.2 ZX 5/2 -1 5/2 -1 4.2/3 0/3 4.2/2 1.2 4.2/2 0 4.2/2 0 SM  22
* $9
9      LEFT FOOT
=YYI 7 YX =15 4.6/2 5.2 8.6/2 9.2 $9                                     SM 23
9      UPPER RIGHT ARM
4NX 0 NXQ 2 KQ 3 2 $3XXI 0 YYI -10 ZZI 56 RA 1.9 5.4 PR .07143 XX 0/2 2. SM 24
*3 .6/2 6 YX -9 -10/2 -12 12/2 ZX 54 47/2 55.6/3 $9                      SM 25
9    UPPER LEFT ARM
=YYI 10 YX 9 10/2 =2 12 $9                                               SM 26
9      MIDDLE RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 48 RA 1.9 XX -12/2 12 -12/2 12 0/2 2.3 YX SM 27
```

```
* -12 12/2 -12 12/2 -9 -10/2 ZX 55.6/3 43.2/3 54 47/2 $9                    SM 28
9     MIDDLE LEFT ARM
=YYI 10 YX =6 9 10/2 $9                                                    SM 29
9     LOWER RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 41 RA 1.4869 PR .0625 XX =3 -12/2 12 0/2    SMA30
*1.8 YX =3 -12 12/2 -10.6 -10.9 -10.6 ZX 43.2/3 33.6/3 40 35.2 40 $9       SMB30
9     LOWER LEFT ARM
=YYI 10 YX =6 10.6 10.9 10.6 $9                                            SM 31
9     RIGHT HAND
4NX 1 KQ 1 $3YYI -10 ZZI 30.5 RA 2.2 PR 3.8 XX =3 0/2 1.4 YX =3 -11/3 ZX   SM 32
* 33.6/3 31 29 31.4 $9                                                     SM 33
9     LEFT HAND
=YYI 10 YX =3 11/3 $9                                                      SM 34
9   HEMISPHERICAL CAP
4NTRNS 1 $3ARY -1 0/3 1 0/3 -1 TX 0 TY -36 TZ 0 $9 MAN MODEL TRANSFORMATION
4MVX 1 NX 1 NXQ 2 KQ 1 1 $3RHX 6.85546 XXI 0 YYI 0 ZZI 66.5 RA 24 25 PR    TC  01
*24 25 XX 0 1 0/7 YX 0 0 1 0 0 24 0 0 25 ZX 42/3 0 1 42 0 1 42 $9          TC  02
9   CYLINDER VACUUM
4MVX 22 NX 2 NXQ 1 KQ 2 $3RHX 0 ZZI 0 XX =4 1 0/4 YX =5 1 0 0 24 ZX =3 -
*42/3 0 1 0 $9
9   CYLINDER ALUMINIUM BLOCK
4MVX 2 $=RHX 6.85546 YX =8 25 RA 25 $9
9   CONICAL VACUUM
3YX =8 24 $9
4MVX 3 NXQ 1 KQ 3 $=RHX 0 PR 1 YYI 0 ZZI -50 ZX -66/3 =3 0 -1 -42 RA 24
9   CONICAL ALUMINUM BLOCK
4MVX 4 $=RHX 6.85546 RA 25 YX =8 25 ZX -67.4142/3 $9                       TC  06
9    CYLINDRICAL CONNECTOR
4MVX 5 NX 2 NXQ 2 KQ 2 2 NTRNS -1 $3RHX 6.85546 RA 12 14 XXI 0 YYI 0 ZZI
  13 XX 0 1 0 0 1 0/7 YX 36/3 -36/3 0 1 0 0 1 0 ZX 0 0 1 0 0 1 0 0 12 0
*0 14 $9
'MVX 0 $9
N12 NZ ZZ RR XD YD ZD ND N2 DHED MD BIN SAC
5DHED 10 DETECTOR IN RIGHT EYE - LEFT MODULE.
>BIN 1 6-664
4ND 1 N2 12 MD 221 NZ 4 $3RR 0 60 80 60 0 ZZ 80 70 0 -70 -80 SAC .1/24 X
*0 4 YD 34.75 ZD 26 $9
5DHED 10 DETECTOR IN ABDOMEN - LEFT MODULE.
=XD 0 YD 36 ZD -1 $9
5DHED 10 DETECTOR IN RIGHT EYE - RIGHT MODULE.
=XD -4 YD -37.25 ZD -26 $9
5DHED 10 DETECTOR IN ABDOMEN - RIGHT MODULE.
=XD 0 YD -36 ZD 1 $9
'ND -1 $9
8
```

GEOMETRY PROGRAM

OUTPUT LISTING

TOTAL NUMBER OF VOLUME ELEMENTS - 51

DETECTOR IN RIGHT EYE - LEFT MODULE.
DETECTOR 1. TOTAL NUMHER OF VECTORS 187. TOTAL SOLID ANGLE 12.56626
DETECTOR MATERIAL 221. COORDINATES - XD = 4.00000 YD = 34.75000 ZD = 26.00000

DETECTOR IN ABDOMEN - LEFT MODULE.
DETECTOR 2. TOTAL NUMBER OF VECTORS 192. TOTAL SOLID ANGLE 12.56624
DETECTOR MATERIAL 221. COORDINATES - XD = 0. YD = 36.00000 ZD = -1.00000

DETECTOR IN RIGHT EYE - RIGHT MODULE.
DETECTOR 3. TOTAL NUMBER OF VECTORS 189. TOTAL SOLID ANGLE 12.56625
DETECTOR MATERIAL 221. COORDINATES - XD = -4.00000 YD = -37.25000 ZD = -26.00000

DETECTOR IN ABDOMEN - RIGHT MODULE.
DETECTOR 4. TOTAL NUMBER OF VECTORS 194. TOTAL SOLID ANGLE 12.56624
DETECTOR MATERIAL 221. COORDINATES - XD = 0. YD = -36.00000 ZD = 1.00000

MATERIAL NUMBERS AND DENSITIES

201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400
201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400
201	2.5400	201	2.5400	201	2.5400	201	2.5400	1	6.8555	22	0.	2	6.8555	3	0.
4	6.8555	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400
201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400
201	2.5400	201	2.5400	201	2.5400	201	2.5400	201	2.5400	1	6.8555	22	0.	2	6.8555
3	0.	4	6.8555	5	6.8555										

TAPE BIN LOCATION IS 6-664

GEOMETRY TEST PROGRAM

INPUT DATA LISTING

```
$      DATA
N18 NX NXQ NVX RHX XXI YYI ZZI XX YX ZX KQ RA PR ARY TX TY TZ NTRNS
9      STANDING MAN MODEL
9      TOP REGION OF HEAD
4NTRNS 1 $3ARY 1 0/3 1 0/3 1 TX 0 TY 36 TZ -42 $9
4NVX 201 NX 1 NXQ 1 KQ 1 $3RHX 2.54 XXI 0 YYI 0 ZZI 70 RA 2.8 PR 2.8 XX      SM 01
*12 0/4 4.8 YX 0/2 12 0/3 ZX 69.2/3 70 71 69.2 $9                            SM 02
9      MAIN REGION OF HEAD
4NX 2 NXQ 3 KQ 3 1 1 $3ZZI 68 RA 2.5 .6/2 PR .25 .6/2 XX =3 -2.4/2 4.8 .     SM 03
 7 1.2 4.8 4.3/2 4 4.3/2 4 YX =3 -12 12/2 0/3 -1.2/2 -1.8 ZX =3 65.2/2 6     SM 04
*2.8 68 66 69.2 68 68.6 68/2 68.6 68 $9                                      SM 05
9      NECK REGION
4NX 2 NXQ 2 KQ 3 2 $3ZZI 62 RA 2 5.4 PR .125 XX -2.4/2 4.8 -12/2 12 0 .2     SM 06
  3.2 .6/2 6 YX -12 12/2 -12 12/2 0/3 -12 12/2 ZX 65.2/2 62.8 55.6/3 61.     SM 07
*4  63/2 55.6/3 $9                                                           SM 08
9      SHOULDERS
4NX 1 KQ 2 3 $3ZZI 58 RA 5.4 8.8 PR 0 .04838 XX -12/2 12 .6/2 6 .6 .4 6     SM 09
*YX -12 12/2 -12 12/2 0/3 ZX 55.6/7 47.4 55.6 $9                             SM 10
9      LOWER CHEST
4NX 2 NXQ 1 KQ 3 $3ZZI 48 RA 6.8 PR .03226 XX =3 -12/2 12 .6 .4 6 ZX =3      SM 11
*43.2/3 55.6 47.4 55.6 $9                                                    SM 12
9      HIP REGION
=ZZI 40 RA 7 PR .0625 XX =6 -.6 0 -6 ZX 43.2/3 33.6/4 43.2 33.6 $9           SM 13
9      UPPER RIGHT LEG
3YYI -4 ZZI 27 RA 3.6 PR .17063 XX =6 -.6 0 -6 YX =6 -3.6 -4.7 -3.6 ZX 3     SM 14
*3.6/3 18.7/3 33.6 18.7 33.6 $9                                              SM 15
9      UPPER LEFT LEG
=YYI 4 YX =6 3.5 4.7 3.5 $9                                                  SM 16
9      LOWER RIGHT LEG
3YYI -5.6 ZZI 12 RA 2.1 PR .06206 XX =6 0/2 2.7 YX =6 -5 -6.2 -4.7 ZX 18     SM 17
*.7/3 4.2/3 16 7.2 18.7 $9                                                   SM 18
9      LOWER LEFT LEG
=YYI 5.6 YX =6 5 6.2 4.7 $9                                                  SM 19
9      RIGHT FOOT
4NX 7 NXQ 0 $3XXI 4 YYI -7 ZZI 2 RA 0 PR 0 XX 9.6/3 -1.8/3 -12/2 12 -12/     SM 20
 2 12 1.8/2 9.6 12 -12/2 12 -12/2 YX =6 -12 12/2 -12 12/2 -12 12/2 -4.6/     SM 21
 2 -5.2 -8.6/2 -9.2 ZX 5/2 -1 5/2 -1 4.2/3 0/3 4.2/2 1.2 4.2/2 0 4.2/2 0     SM 22
* $9
9      LEFT FOOT
=YYI 7 YX =15 4.6/2 5.2 8.6/2 9.2 $9                                         SM 23
9      UPPER RIGHT ARM
4NX 0 NXQ 2 KQ 3 2 $3XXI 0 YYI -10 ZZI 56 RA 1.9 5.4 PR .07143 XX 0/2 2.     SM 24
*3 .6/2 6 YX -9 -10/2 -12 12/2 ZX 54 47/2 55.6/3 $9                          SM 25
9      UPPER LEFT ARM
=YYI 10 YX 9 10/2 =2 12 $9                                                   SM 26
9      MIDDLE RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 48 RA 1.9 XX -12/2 12 -12/2 12 0/2 2.3 YX     SM 27
* -12 12/2 -12 12/2 -9 -10/2 ZX 55.6/3 43.2/3 54 47/2 $9                     SM 28
9      MIDDLE LEFT ARM
=YYI 10 YX =6 9 10/2 $9                                                      SM 29
9      LOWER RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 41 RA 1.4869 PR .0625 XX =3 -12/2 12 0/2      SMA30
*1.8 YX =3 -12 12/2 -10.6 -10.9 -10.6 ZX 43.2/3 33.6/3 40 35.2 40 $9         SMB30
9      LOWER LEFT ARM
=YYI 10 YX =6 10.6 10.9 10.6 $9                                              SM 31
9      RIGHT HAND
4NX 1 KQ 1 $3YYI -10 ZZI 30.5 RA 2.2 PR 3.8 XX =3 0/2 1.4 YX =3 -11/3 ZX     SM 32
* 33.6/3 31 29 31.4 $9                                                       SM 33
9      LEFT HAND
=YYI 10 YX =3 11/3 $9                                                        SM 34
```

```
9   HEMISPHERICAL CAP
4NTRNS 1 $3ARY 1 0/3 1 0/3 1 TX 0 TY 36 TZ 0 $9  MAN MODEL TRANSFORMATIO  N
4MVX 1 NX 1 NXQ 2 KQ 1 1 $3RHX 6.85546 XXI 0 YYI 0 ZZI 66.5 RA 24 25 PR   TC  01
*24 25 XX 0 1 0/7 YX 0 0 1 0 0 24 0 0 25 ZX 42/3 0 1 42 0 1 42 $9         TC  02
9   CYLINDER VACUUM
4MVX 22 NX 2 NXQ 1 KQ 2 $3RHX 0 ZZI 0 XX =4 1 0/4 YX =5 1 0 0 24 ZX =3 -
*42/3 0 1 0 $9
9   CYLINDER ALUMINIUM BLOCK
4MVX 2 $=RHX 6.85546 YX =8 25 RA 25 $9
9   CONICAL VACUUM
3YX =8 24 $9
4MVX 3 NXQ 1 KQ 3 $=RHX 0 PR 1 YYI 0 ZZI -50 ZX -66/3 =3 0 -1 -42 RA 24
9   CONICAL ALUMINUM BLOCK
4MVX 4 $=RHX 6.85546 RA 25 YX =8 25 ZX -67.4142/3 $9                      TC  06
9     STANDING MAN MODEL
4NTRNS 1 $3ARY -1 0/3 1 0/3 -1 TX 0 TY -36 TZ 42 $9
9     TOP REGION OF HEAD
4MVX 201 NX 1 NXQ 1 KQ 1 $3RHX 2.54 XXI 0 YYI 0 ZZI 70 RA 2.8 PR 2.8 XX    SM  01
*12 0/4 4.8 YX 0/2 12 0/3 ZX 69.2/3 70 71 69.2 $9                          SM  02
9     MAIN REGION OF HEAD
4NX 2 NXQ 3 KQ 3 1 1 $3ZZI 68 RA 2.5 .6/2 PR .25 .6/2 XX =3 -2.4/2 4.8 .   SM  03
 7 1.2 4.8 4.3/2 4 4.3/2 4 YX =3 -12 12/2 0/3 -1.2/2 -1.8 ZX =3 65.2/2 6   SM  04
*2.8 68 66 69.2 68 69.6 68/2 68.6 68 $9                                    SM  05
9     NECK REGION
4NX 2 NXQ 2 KQ 3 2 $3ZZI 62 RA 2 5.4 PR .125 XX -2.4/2 4.8 -12/2 12 0 .2   SM  06
  3.2 .6/2 6 YX -12 12/2 -12 12/2 0/3 -12 12/2 ZX 65.2/2 62.8 55.6/3 61.   SM  07
*4  63/2 55.6/3 $9                                                         SM  08
9     SHOULDERS
4NX 1 KQ 2 3 $3ZZI 58 RA 5.4 8.8 PR 0 .04838 XX -12/2 12 .6/2 6 .6 .4 6   SM  09
*YX -12 12/2 -12 12/2 0/3 ZX 55.6/7 47.4 55.6 $9                           SM  10
9     LOWER CHEST
4NX 2 NXQ 1 KQ 3 $3ZZI 48 RA 6.8 PR .03226 XX =3 -12/2 12 .6 .4 6 ZX =3    SM  11
*43.2/3 55.6 47.4 55.6 $9                                                  SM  12
9     HIP REGION
=ZZI 40 RA 7 PR .0625 XX =6 -.6 0 -6 ZX 43.2/3 33.6/4 43.2 33.6 $9         SM  13
9     UPPER RIGHT LEG
3YYI -4 ZZI 27 RA 3.6 PR .17963 XX =6 -.6 0 -6 YX =6 -3.6 -4.7 -3.6 ZX 3   SM  14
*3.6/3 18.7/3 33.6 18.7 33.6 $9                                            SM  15
9     UPPER LEFT LEG
=YYI 4 YX =6 3.5 4.7 3.5 $9                                                SM  16
9     LOWER RIGHT LEG
3YYI -5.6 ZZI 12 RA 2.1 PR .06206 XX =6 0/2 2.7 YX =6 -5 -6.2 -4.7 ZX 18   SM  17
*.7/3 4.2/3 16 7.2 18.7 $9                                                 SM  18
9     LOWER LEFT LEG
=YYI 5.6 YX =6 5 6.2 4.7 $9                                                SM  19
9     RIGHT FOOT
4NX 7 NXQ 0 $3XXI 4 YYI -7 ZZI 2 RA 0 PR 0 XX 9.6/3 -1.8/3 -12/2 12 -12/   SM  20
 2 12 1.8/2 9.6 12 -12/2 12 -12/2 YX =6 -12 12/2 -12 12/2 -12 12/2 -4.6/   SM  21
 2 -5.2 -8.6/2 -9.2 ZX 5/2 -1 5/2 -1 4.2/3 0/3 4.2/2 1.2 4.2/2 0 4.2/2 0   SM  22
* $9
9     LEFT FOOT
=YYI 7 YX =15 4.6/2 5.2 8.6/2 9.2 $9                                       SM  23
9     UPPER RIGHT ARM
4NX 0 NXQ 2 KQ 3 2 $3XXI 0 YYI -10 ZZI 56 RA 1.9 5.4 PR .07143 XX 0/2 2.   SM  24
*3 .6/2 6 YX -9 -10/2 -12 12/2 ZX 54 47/2 55.6/3 $9                        SM  25
9   UPPER LEFT ARM
=YYI 10 YX 9 10/2 =2 12 $9                                                 SM  26
9     MIDDLE RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 48 RA 1.9 XX -12/2 12 -12/2 12 0/2 2.3 YX   SM  27
* -12 12/2 -12 12/2 -9 -10/2 ZX 55.6/3 43.2/3 54 47/2 $9                   SM  28
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9      MIDDLE LEFT ARM
=YYI 10 YX =6 9 10/2 $9                                                    SM 29
9      LOWER RIGHT ARM
4NX 2 NXQ 1 KQ 3 $3YYI -10 ZZI 41 RA 1.4869 PR .0625 XX =3 -12/2 12 0/2    SMA30
*1.8 YX =3 -12 12/2 -10.6 -10.9 -10.6 ZX 43.2/3 33.6/3 40 35.2 40 $9       SMB30
9      LOWER LEFT ARM
=YYI 10 YX =6 10.6 10.9 10.6 $9                                            SM 31
9      RIGHT HAND
4NX 1 KQ 1 $3YYI -10 ZZI 30.5 RA 2.2 PR 3.8 XX =3 0/2 1.4 YX =3 -11/3 ZX   SM 32
* 33.6/3 31 29 31.4 $9                                                     SM 33
9      LEFT HAND
=YYI 10 YX =3 11/3 $9                                                      SM 34
9   HEMISPHERICAL CAP
4NTRNS 1 $3ARY -1 0/3 1 0/3 -1 TX 0 TY -36 TZ 0 $9 MAN MODEL TRANSFORMATION
4MVX 1 NX 1 NXQ 2 KQ 1 1 $3RHX 6.85546 XXI 0 YYI 0 ZZI 66.5 RA 24 25 PR    TC  01
*24 25 XX 0 1 0/7 YX 0 0 1 0 0 24 0 0 25 ZX 42/3 0 1 42 0 1 42 $9          TC  02
9   CYLINDER VACUUM
4MVX 22 NX 2 NXQ 1 KQ 2 $3RHX 0 ZZI 0 XX =4 1 0/4 YX =5 1 0 0 24 ZX =3 -
*42/3 0 1 0 $9
9   CYLINDER ALUMINIUM BLOCK
4MVX 2 $=RHX 6.85546 YX =8 25 RA 25 $9
9   CONICAL VACUUM
3YX =8 24 $9
4MVX 3 NXQ 1 KQ 3 $=RHX 0 PR 1 YYI 0 ZZI -50 ZX -66/3 =3 0 -1 -42 RA 24
9   CONICAL ALUMINUM BLOCK
4MVX 4 $=RHX 6.85546 RA 25 YX =8 25 ZX -67.4142/3 $9                       TC  06
2   CYLINDRICAL CONNECTOR
4MVX 5 NX 2 NXQ 2 KQ 2 2 NTRNS -1 $3RHX 6.85546 RA 12 14 XXI 0 YYI 0 ZZI
  13 XX 0 1 0 0 1 0/7 YX 36/3 -36/3 0 1 0 0 1 0 ZX 0 0 1 0 0 1 0 0 12 0
*0 14 $9
'MVX 0 $9
N11 X Y Z NH NV KIND NTRNS ARY TX TY TZ
5KIND 10 TEST CASE.    X = 0.0
4NTRNS -1 NH 130 NV -1 $=X 0/3 Y -65 65 -65 Z 70/2 -70 $9
5KIND 10 TEST CASE.    Y = 36.0
=X -30 30 -30 Y 36/3 Z 70/2 -70 $9
'NH 0 $9
8
```
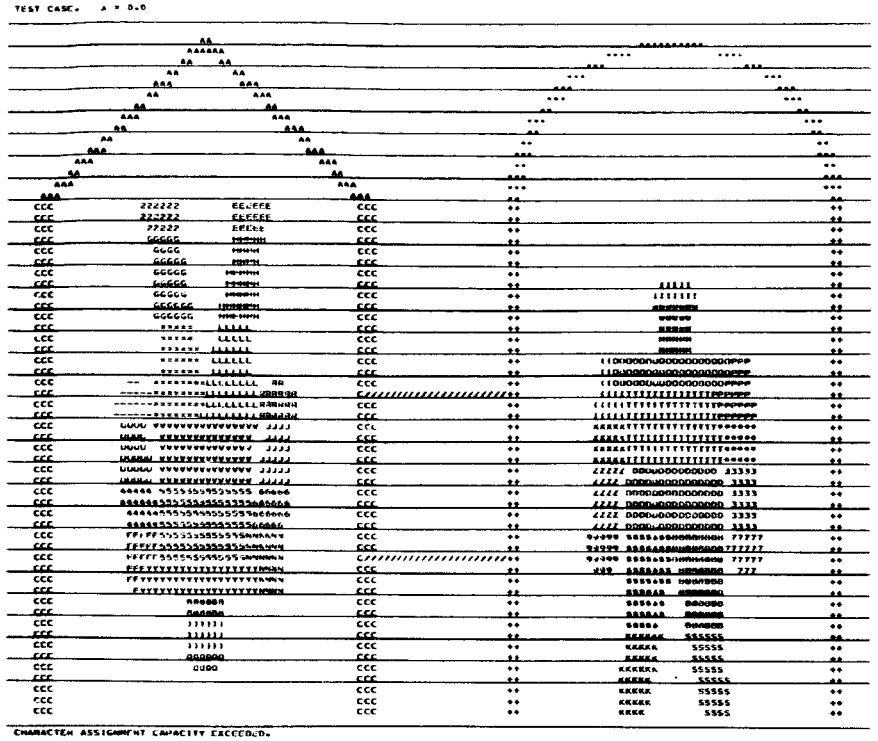

GEOMETRY TEST PROGRAM

OUTPUT LISTING

TEST CASE. A = 0.0

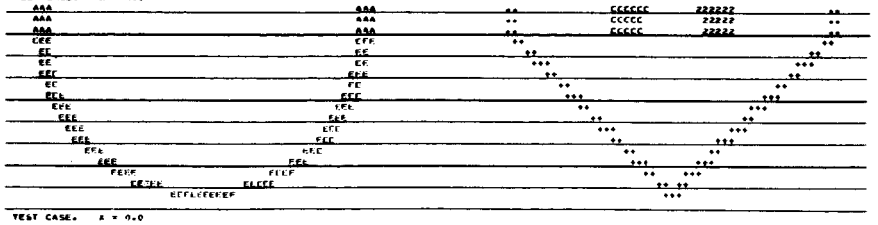


CHARACTER ASSIGNMENT CAPACITY EXCEEDED.

TEST CASE. A = 0.0

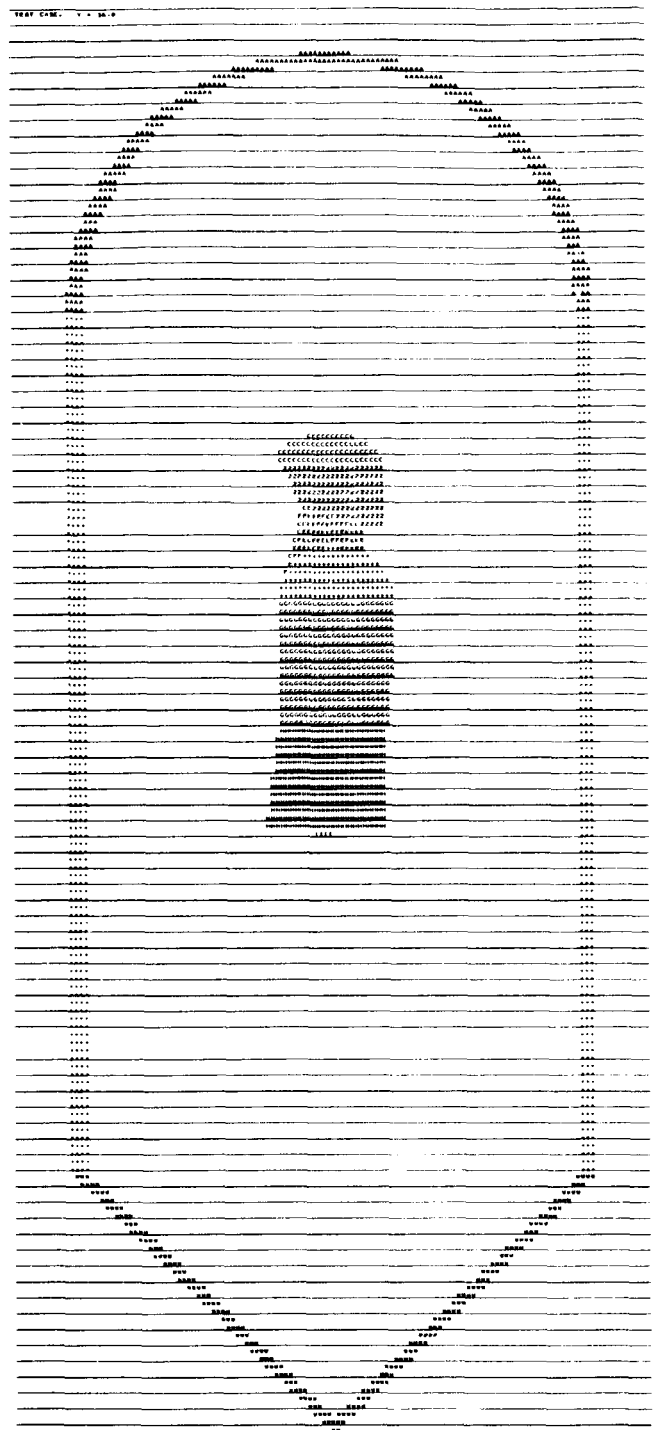
SYMBOL TABLE	MATERIAL NO.	*DENSITY*	VOLUME
A	0	6.855+00	56
.	1	6.955+00	21
C	2	8.855+00	68
2	201	2.540+00	36
E	201	2.540+00	37
+	2	6.855+00	73
N	201	2.540+00	26
M	201	2.540+00	75
I	201	2.540+00	1
W	201	2.540+00	2
-	201	2.540+00	32
L	201	2.540+00	33
R	201	2.540+00	3
(	201	2.540+00	11
U	201	2.540+00	4
P	201	2.540+00	14
=	201	2.540+00	08
H	201	2.540+00	45
/	2	8.855+00	51
'	201	2.540+00	5
U	201	2.540+00	42
V	201	2.540+00	31
J	201	2.540+00	41
W	201	2.540+00	15
B	201	2.540+00	16
<	201	2.540+00	17
O	201	2.540+00	A
1	201	2.540+00	1A
A	201	2.540+00	40
5	201	2.540+00	30
6	201	2.540+00	61
F	201	2.540+00	38
N	201	2.540+00	39
9	201	2.540+00	19
A	201	2.540+00	7
8	201	2.540+00	A
7	201	2.540+00	70
Y	201	2.540+00	79
0	201	2.540+00	28
3	201	2.540+00	27
K	201	2.540+00	0
:	201	2.540+00	10
O	201	2.540+00	26

TEST CASE. A = 0.0



TEST CASE. A = 0.0

SYMBOL TABLE	MATERIAL NO.	*DENSITY*	VOLUME
A	2	6.855+00	68
.	2	6.955+00	73
C	201	2.540+00	11
2	201	2.540+00	12
E	1	8.855+00	66
+	4	6.855+00	25



TEST CASE. Y = 30.0

SYMBOL	TABLE	MATERIAL NO.	*DENSITY*	VOLUME
A		1	6.850E+00	21
*		2	6.850E+00	28
C		201	2.540E+00	1
2		201	2.540E+00	2
E		201	2.540E+00	3
+		201	2.540E+00	4
G		201	2.540E+00	5
H		201	2.540E+00	6
I		201	2.540E+00	7
#		4	6.850E+00	25

DOSE PROGRAM

INPUT DATA LISTING

```
*     DATA
N16 PHI E MAT SA SB R1 HEAD NPHI NM N2 ND BIN FDC UNITS FF AT
5HEAD 20 TEST CASE.   MARS MISSION - 20 DAY STAY - TOTAL DURATION 442 DA
 YS.   LAUNCH, OCT. 9, 1977.  DELTA T = 1 DAY.
5UNITS 3  RADS/MISSION
5BIN 1 6-664
4NM 7 MAT 1 2 3 4 5 201 221 N2 12 ND 4 $9
3R1 1.75/6 1.8 SA 3.1-3/5 2.32-3 1.943-3 SB 1.9-6/5 1.2-6 2.273-6 AT 0/2
 0 $9
4NPHI 8 $3E 10 30 80 150 300 500 700 1+3 PHI 3.0459+7 3.355+6 4.7361+5 1
 .3549+5 3.4156+4 1.2384+4 6.3506+3 3.1293+3 $9
3FDC 1.6-8 $9
=FF 1/7 $9
N4 NAR POLA AZIM NSKIP
4NSKIP 1 NAR 5 $3POLA 0 180 20 160 40 140 60 120 80 100 AZIM 0 180 20 16
*0 40 140 60 120 80 400 $9
=
=
=
'ND -1 $9
8
```

DOSE PROGRAM

OUTPUT LISTING

MATERIALS LIST FOR THIS CASE

MATERIAL	SA	SB	FF	R1	AT
1	3.1000-03	1.9000-06	1.0000+00	1.7500+00	0.
2	3.1000-03	1.9000-06	1.0000+00	1.7500+00	0.
3	3.1000-03	1.9000-06	1.0000+00	1.7500+00	0.
4	3.1000-03	1.9000-06	1.0000+00	1.7500+00	0.
5	3.1000-03	1.9000-06	1.0000+00	1.7500+00	0.
201	2.3200-03	1.2000-06	1.0000+00	1.7500+00	0.
221	1.9430-03	2.2730-06	1.0000+00	1.8000+00	0.

TEST CASE. MARS MISSION - 20 DAY STAY - TOTAL DURATION 442 DAYS. LAUNCH, OCT. 9, 1977. DELTA T = 1 DAY.

E(I)	PHI(I)	H(I)	Q(I)
1.00000+01	3.04590+07	3.10198+09	2.00792+00
3.00000+01	3.35500+06	2.97960+09	1.99609+00
8.00000+01	4.73610+05	2.91240+09	1.99088+00
1.50000+02	1.35490+05	2.87027+09	1.98798+00
3.00000+02	3.41560+04	2.83917+09	1.98607+00
5.00000+02	1.23840+04	2.81628+09	1.98488+00
7.00000+02	6.35060+03	2.80713+09	1.98427+00
1.00000+03	3.12930+03	-0.00000-20	-0.00000-20

DETECTOR IN RIGHT EYE - LEFT MODULE.
XD = 4.000 YD = 34.750 ZD = 26.000
DETECTOR MATERIAL NUMBER IS 221

DETECTOR 1 TOTAL DOSE - 3.656+01 RADS/MISSION *****

POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
0.	0.			
180.00	180.00	1.605+01	1.417+00	6.278+00
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
20.00	20.00			
160.00	160.00	1.101+01	1.401+00	4.357+00
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
40.00	40.00			
140.00	140.00	4.465+00	1.245+00	1.987+00
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
60.00	60.00			
120.00	120.00	1.649+00	1.322+00	6.916-01
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
80.00	80.00			
100.00	800.00	1.859+00	1.161+00	8.877-01
		1.972+01	1.802+00	6.065+00

DETECTOR IN ABDOMEN - LEFT MODULE.
XD = 0. YD = 36.000 ZD = -1.000
DETECTOR MATERIAL NUMBER IS 221

DETECTOR 2 TOTAL DOSE - 1.306+01 RADS/MISSION *****

POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
0.	0.			
180.00	180.00	7.123+00	1.626+00	6.551+00
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
20.00	20.00			
160.00	160.00	3.996+00	1.508+00	3.961+00
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
40.00	40.00			
140.00	140.00	1.906+00	1.457+00	1.956+00
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
60.00	60.00			
120.00	120.00	7.151-01	1.497+00	7.143-01
POLA	AZIM	PARTIAL DOSE	WT. FRACTION	SOLID ANGLE
80.00	80.00			
100.00	400.00	6.421-01	1.573+00	6.102-01
		5.650+00	1.475+00	5.729+00

DETECTOR IN RIGHT EYE - RIGHT MODULE.
XD = -4.000 YD = -37.250 ZD = -26.000
DETECTOR MATERIAL NUMBER IS 221

```
DETECTOR   3      TOTAL DOSE -    3.848+01 RADS/MISSION   *****

  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
    0.       0.
 180.00   180.00      1.466+01       1.167+00      6.249+00
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  20.00    20.00
 160.00   160.00      8.532+00       1.047+00      4.051+00
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  40.00    40.00
 140.00   140.00      3.732+00       1.010+00      1.837+00
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  60.00    60.00
 120.00   120.00      9.441-01       8.238-01      5.697-01
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  80.00    80.00
 100.00   400.00      3.639+00       2.226+00      8.127-01
                      2.039+01       1.806+00      5.611+00

DETECTOR IN ABDOMEN - RIGHT MODULE.
XD =      0.          YD =    -36.000      ZD =      1.000
DETECTOR MATERIAL NUMBER IS 221

DETECTOR   4      TOTAL DOSE -    1.304+01 RADS/MISSION   *****

  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
    0.       0.
 180.00   180.00      5.898+00       1.480+00      6.015+00
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  20.00    20.00
 160.00   160.00      3.424+00       1.369+00      3.775+00
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  40.00    40.00
 140.00   140.00      1.929+00       1.296+00      2.246+00
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  60.00    60.00
 120.00   120.00      3.942-01       8.611-01      6.909-01
  POLA     AZIM   PARTIAL DOSE   WT. FRACTION   SOLID ANGLE
  80.00    80.00
 100.00   400.00      1.565+00       1.764+00      1.339+00
                      5.923+00       1.591+00      5.619+00



THE FOLLOWING (CARD/CARDS) (IS/ARE) IN ERROR.

*ND -1 $9
```

MISSION FLUX PROGRAM

INPUT DATA LISTING

```
*      DATA
-3055.     -227.
-152.       302.      +158.
+118.      -191.      +126.      +91.
+95.       +80.       +58.       -38.       +31.
-27.        32.        20.       -4.        -15.       -7.
 10.         5.         2.       -24.       -3.                  -11.

           +590.
           -190.      +24.
           -45.       +29.       -9.
           +15.       -31.       -4.        -17.
           +2.        +10.       -5.        -14.       +9.
           -2.        +11.                  -1.        -3.        -1.
NOTE...THE B-L FLUX MAPS ARE OMITTED IN ORDER TO SAVE APPROXIMATELY
      25 PAGES.  THE FLUX DATA ARE THOSE DEVELOPED BY DR JAMES VETTE
      OF THE AEROSPACE CORPORATION.  FLUX TABLES ARE ORDERED AS FOLLOWS.
        1.  EXPONENTIAL ENERGY PARAMETER FOR PROTONS ABOVE 50 MEV
        2.  PROTON MAP AP4
        3.  PROTON MAP AP2
        4.  PROTON MAP AP1
        5.  PROTON MAP AP3
        6.  ELECTRON SPECTRUM VERSUS L
        7.  ELECTRON MAP AE1
2 100.05
0.          90.       1000.      -1.        2.         0.         1.   1.
4
```

MISSION FLUX PROGRAM

OUTPUT LISTING

T	X(T)	Y(T)	Z(T)	T	X(T)	Y(T)	Z(T)
0.	3.448-08	1.157+00	0.	6.363+01	-5.357-03	1.155+00	7.338-02
1.273+02	-1.065-02	1.148+00	1.465-01	1.909+02	-1.581-02	1.136+00	2.190-01
2.545+02	-2.078-02	1.120+00	2.906-01	3.181+02	-2.550-02	1.099+00	3.610-01
3.818+02	-2.990-02	1.074+00	4.300-01	4.454+02	-3.392-02	1.044+00	4.973-01
5.090+02	-3.752-02	1.010+00	5.625-01	5.726+02	-4.063-02	9.724-01	6.255-01
6.363+02	-4.321-02	9.307-01	6.860-01	6.999+02	-4.521-02	8.851-01	7.437-01
7.635+02	-4.660-02	8.360-01	7.984-01	8.271+02	-4.732-02	7.836-01	8.499-01
8.908+02	-4.735-02	7.280-01	8.980-01	9.544+02	-4.667-02	6.695-01	9.424-01
1.018+03	-4.524-02	6.083-01	9.831-01	1.082+03	-4.305-02	5.447-01	1.020+00
1.145+03	-4.009-02	4.789-01	1.052+00	1.209+03	-3.635-02	4.113-01	1.081+00
1.273+03	-3.183-02	3.420-01	1.105+00	1.336+03	-2.653-02	2.715-01	1.124+00
1.400+03	-2.047-02	1.999-01	1.139+00	1.463+03	-1.366-02	1.275-01	1.150+00
1.527+03	-6.117-03	5.471-02	1.156+00	1.591+03	2.124-03	-1.823-02	1.157+00
1.654+03	1.103-02	-9.102-02	1.153+00	1.718+03	2.057-02	-1.634-01	1.145+00
1.782+03	3.070-02	-2.350-01	1.132+00	1.845+03	4.136-02	-3.055-01	1.115+00
1.909+03	5.250-02	-3.747-01	1.093+00	1.972+03	6.407-02	-4.424-01	1.067+00
2.036+03	7.600-02	-5.081-01	1.037+00	2.100+03	8.823-02	-5.717-01	1.002+00
2.163+03	1.007-01	-6.329-01	9.632-01	2.227+03	1.133-01	-6.914-01	9.207-01
2.291+03	1.260-01	-7.471-01	8.744-01	2.354+03	1.386-01	-7.996-01	8.246-01
2.418+03	1.512-01	-8.489-01	7.714-01	2.481+03	1.637-01	-8.946-01	7.152-01
2.545+03	1.758-01	-9.366-01	6.561-01	2.609+03	1.877-01	-9.747-01	5.943-01
2.672+03	1.991-01	-1.009+00	5.301-01	2.736+03	2.101-01	-1.039+00	4.639-01
2.800+03	2.204-01	-1.065+00	3.957-01	2.863+03	2.301-01	-1.086+00	3.260-01
2.927+03	2.390-01	-1.103+00	2.549-01	2.990+03	2.472-01	-1.115+00	1.828-01
3.054+03	2.544-01	-1.123+00	1.100-01	3.118+03	2.606-01	-1.127+00	3.671-02
3.181+03	2.659-01	-1.125+00	-3.671-02	3.245+03	2.700-01	-1.120+00	-1.100-01
3.309+03	2.730-01	-1.109+00	-1.828-01	3.372+03	2.747-01	-1.095+00	-2.549-01
3.436+03	2.752-01	-1.075+00	-3.260-01	3.499+03	2.744-01	-1.052+00	-3.957-01
3.563+03	2.723-01	-1.024+00	-4.639-01	3.627+03	2.688-01	-9.926-01	-5.301-01
3.690+03	2.639-01	-9.569-01	-5.943-01	3.754+03	2.576-01	-9.175-01	-6.561-01
3.818+03	2.499-01	-8.744-01	-7.152-01	3.881+03	2.408-01	-8.279-01	-7.714-01
3.945+03	2.303-01	-7.782-01	-8.246-01	4.008+03	2.183-01	-7.255-01	-8.744-01
4.072+03	2.050-01	-6.700-01	-9.207-01	4.136+03	1.904-01	-6.119-01	-9.632-01
4.199+03	1.744-01	-5.516-01	-1.002+00	4.263+03	1.572-01	-4.891-01	-1.037+00
4.327+03	1.387-01	-4.249-01	-1.067+00	4.390+03	1.191-01	-3.592-01	-1.093+00
4.454+03	9.838-02	-2.922-01	-1.115+00	4.517+03	7.665-02	-2.242-01	-1.132+00
4.581+03	5.399-02	-1.556-01	-1.145+00	4.645+03	3.047-02	-8.648-02	-1.153+00
4.708+03	6.180-03	-1.729-02	-1.157+00	4.772+03	-1.877-02	5.175-02	-1.156+00
4.836+03	-4.429-02	1.203-01	-1.150+00	4.899+03	-7.026-02	1.882-01	-1.139+00
4.963+03	-9.657-02	2.551-01	-1.124+00	5.027+03	-1.231-01	3.207-01	-1.105+00
5.090+03	-1.498-01	3.848-01	-1.081+00	5.154+03	-1.764-01	4.471-01	-1.052+00
5.217+03	-2.029-01	5.073-01	-1.020+00	5.281+03	-2.291-01	5.653-01	-9.831-01
5.345+03	-2.550-01	6.208-01	-9.424-01	5.408+03	-2.803-01	6.735-01	-8.980-01
5.472+03	-3.050-01	7.233-01	-8.499-01	5.536+03	-3.289-01	7.700-01	-7.984-01
5.599+03	-3.519-01	8.134-01	-7.437-01	5.663+03	-3.739-01	8.534-01	-6.860-01
5.726+03	-3.947-01	8.897-01	-6.255-01	5.790+03	-4.143-01	9.222-01	-5.625-01
5.854+03	-4.325-01	9.509-01	-4.973-01	5.917+03	-4.492-01	9.756-01	-4.300-01
5.981+03	-4.643-01	9.963-01	-3.610-01	6.045+03	-4.778-01	1.013+00	-2.906-01
6.108+03	-4.894-01	1.025+00	-2.190-01	6.172+03	-4.992-01	1.033+00	-1.465-01
6.235+03	-5.071-01	1.037+00	-7.338-02	6.299+03	-5.129-01	1.037+00	-3.147-06

TRAJECTORY AND FLUX IN B-L SPACE

T	B(T)	L(T)	PROTON FLUX(T)	ELECTRON FLUX(T)	KTR
0.	0.18968	1.2042	5.0170+03	2.4590+07	3
0.636+02	0.19296	1.1783	2.0438+03	1.9084+07	2
0.127+03	0.19765	1.1748	1.1152+03	7.6669+06	2
0.191+03	0.20381	1.1896	8.4852+02	2.2978+06	4
0.255+03	0.21140	1.2115	6.9909+02	8.4977+05	6
0.318+03	0.22027	1.2460	5.0138+02	4.1140+05	11
0.382+03	0.23019	1.2949	4.5302+02	2.4431+05	15
0.445+03	0.24087	1.3617	2.2857+02	5.8335+04	20
0.509+03	0.25198	1.4496	8.4585+01	3.5118+04	26
0.573+03	0.26318	1.5638	4.2871+00	1.8786+04	33
0.636+03	0.27420	1.7109	1.0000+00	8.6423+03	39
0.700+03	0.28480	1.8974	1.0000+00	2.0169+03	49
0.764+03	0.29483	2.1342	1.0000+00	1.3302+03	59
0.827+03	0.30422	2.4352	1.0000+00	1.3455+03	71
0.891+03	0.31295	0.	0.	0.	0
0.954+03	0.32111	0.	0.	0.	0
0.102+04	0.32879	0.	0.	0.	0
0.108+04	0.33610	0.	0.	0.	0
0.115+04	0.34316	0.	0.	0.	0
0.121+04	0.	0.	0.	0.	0
0.127+04	0.	0.	0.	0.	0
0.134+04	0.	0.	0.	0.	0
0.140+04	0.	0.	0.	0.	0
0.146+04	0.	0.	0.	0.	0
0.153+04	0.	0.	0.	0.	0
0.159+04	0.	0.	0.	0.	0
0.165+04	0.	0.	0.	0.	0
0.172+04	0.	0.	0.	0.	0
0.178+04	0.	0.	0.	0.	0
0.185+04	0.	0.	0.	0.	0
0.191+04	0.	0.	0.	0.	0
0.197+04	0.36833	0.	0.	0.	0
0.204+04	0.35998	0.	0.	0.	0
0.210+04	0.35026	0.	0.	0.	0
0.216+04	0.33946	0.	0.	0.	0
0.223+04	0.32786	0.	0.	0.	0
0.229+04	0.31577	0.	0.	0.	0
0.235+04	0.30346	2.1235	1.0000+00	4.0967+02	59
0.242+04	0.29119	1.9149	1.0000+00	2.5653+02	50
0.248+04	0.27918	1.7486	1.0000+00	5.4330+01	41
0.255+04	0.26763	1.6141	1.5269+00	1.7282+04	35
0.261+04	0.25670	1.5044	4.9383+01	4.5860+04	29
0.267+04	0.24657	1.4146	2.1305+02	6.3223+04	23
0.274+04	0.23740	1.3408	2.7791+02	8.9619+04	18
0.280+04	0.22941	1.2801	3.1019+02	1.6928+05	15
0.286+04	0.22286	1.2311	1.9058+02	1.4427+05	11
0.293+04	0.21805	1.1929	1.1642+02	1.2715+05	6
0.299+04	0.21528	1.1637	3.9791+01	1.1562+05	4
0.305+04	0.21481	1.1398	1.1875+01	7.3215+04	2
0.312+04	0.21680	1.1338	6.9977+00	3.5021+04	2
0.318+04	0.22126	1.1466	8.2315+00	1.3738+04	3
0.324+04	0.22805	1.1662	8.0315+00	3.6164+03	5
0.331+04	0.23688	1.1959	1.0000+00	3.7672+02	9
0.337+04	0.24736	1.2356	2.1397+00	1.5025+01	13
0.344+04	0.25909	1.2875	1.0000+00	1.0488+00	17
0.350+04	0.27167	1.3535	1.0000+00	1.0000+00	22
0.356+04	0.28473	1.4364	1.0000+00	1.0000+00	28
0.363+04	0.29798	1.5391	1.0000+00	1.0000+00	34
0.369+04	0.31118	0.	0.	0.	0
0.375+04	0.32417	0.	0.	0.	0
0.382+04	0.33678	0.	0.	0.	0
0.388+04	0.34890	0.	0.	0.	0
0.394+04	0.36039	0.	0.	0.	0
0.401+04	0.37110	0.	0.	0.	0
0.407+04	0.38088	0.	0.	0.	0
0.414+04	0.38954	0.	0.	0.	0
0.420+04	0.39686	0.	0.	0.	0
0.426+04	0.40264	0.	0.	0.	0
0.433+04	0.40667	0.	0.	0.	0
0.439+04	0.	0.	0.	0.	0
0.445+04	0.	0.	0.	0.	0
0.452+04	0.	0.	0.	0.	0
0.458+04	0.	0.	0.	0.	0
0.464+04	0.	0.	0.	0.	0
0.471+04	0.	0.	0.	0.	0
0.477+04	0.	0.	0.	0.	0
0.484+04	0.	0.	0.	0.	0
0.490+04	0.	0.	0.	0.	0
0.496+04	0.	0.	0.	0.	0
0.503+04	0.	0.	0.	0.	0
0.509+04	0.	0.	0.	0.	0
0.515+04	0.29277	5.2132	1.0000+00	0.	152
0.522+04	0.27897	4.5381	1.0000+00	0.	132
0.528+04	0.26624	3.9998	1.0000+00	0.	116
0.534+04	0.25485	3.5628	1.0000+00	0.	102
0.541+04	0.24502	3.2013	1.0000+00	3.6711+03	91
0.547+04	0.23685	2.8967	1.3457+01	2.3724+03	80
0.554+04	0.23033	2.6359	1.9350+02	5.0275+03	71
0.560+04	0.22531	2.4095	8.5463+02	1.3199+04	63
0.566+04	0.22159	2.2109	1.5674+03	4.3467+04	55
0.573+04	0.21885	2.0358	3.0266+03	1.6132+05	48
0.579+04	0.21677	1.8810	4.8122+03	4.0470+05	41
0.585+04	0.21505	1.7441	6.1108+03	9.1784+05	35
0.592+04	0.21343	1.6236	7.2570+03	1.8524+06	30
0.598+04	0.21173	1.5189	9.0965+03	3.5238+06	25
0.604+04	0.20988	1.4291	1.0792+04	6.6944+06	20
0.611+04	0.20797	1.3534	1.1367+04	1.0591+07	16
0.617+04	0.20619	1.2895	9.2373+03	1.1627+07	13
0.624+04	0.20487	1.2382	2.9771+03	4.5674+06	8
0.630+04	0.20441	1.1983	1.1540+03	2.2125+06	5

E	PROTON INTEGRAL FLUX
4.	4.9512+06
15.	9.3721+05
34.	6.3456+05
50.	4.6250+05
75.	4.1414+05
100.	3.7570+05
150.	3.1499+05
200.	2.6835+05
300.	2.0169+05
400.	1.5730+05
600.	1.0394+05
1000.	5.5153+04

E	ELECTRON INTEGRAL FLUX
0.50	5.5152+09
1.00	4.2119+09
2.00	1.9606+09
3.00	8.0920+08
4.00	3.3154+08
5.00	1.3820+08
6.00	5.7612+07
7.00	2.3920+07

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